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A Surrogate Measure to Assess Safety Condition at Different Signalized Intersections

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صدق الله العظيم

سورة الفاتحة الآية (2)

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Acknowledgments

DEDICATION

I dedicate my thesis to

My cousin's soul

Abstract

Traffic safety is an essential aspect of transportation engineering. Otherwise, there is no benefit to a traffic facility that lacks safety. Despite this, most road engineers in developing countries ignore traffic safety in their designs or adopt traditional methods that are characterized as weak in their assessment of safety.

This study offers an assessment of traffic safety at three signalized intersections in Hilla city's urban areas, using a simulation approach, simulation approach includes the coupling of software for simulation traffic with a Surrogate Safety Assessment Model (SSAM). Visual Simulation Model (VISSIM) (Ver.10, 2020) is used to generate trajectory (trj) files that simulate geometric, traffic, and signal conditions to represent the real world of the studied locations.

VISSIM is calibrated then the simulated (trj) files are exported to SSAM's model. SSAM took over analyses of those files and calculated surrogate safety measures, involving Times-To-Collision (TTC), Post Encroachments Times (PET), and Deceleration Rates (DR). TTC is mainly relied on to evaluate the conflicts severity level and thus evaluate the risk of the intersections.

The conflicts are categorized into three main types depending on the collisions angles for conflicting vehicles, (Rear-end "RE", Lane- change "LC", and Crossing "C") conflicts. The number of traffic conflicts, severity, and places of occurrence of these conflicts are extracted from the SSAM model. The Pearson Correlation Coefficient (PCC) is calculated between field conflicts and simulated to validate the conflicts extracted from VISSIM & SSAM software.

The results showed that VISSIM calibration decreased Mean Absolute Prevention Error (MAPE) from 59% to 33% from total conflicts. The

optimal values of the main safety indicators TTC and PET, ranged (1.5-1.8) s and (4.7-5.3) s respectively. Rear-end conflicts prevailed in all sites until they reached 55% of all conflicts. A greater number of conflicts occurred at the 40 St. Intersection is 81, 73 for Bab- Al Hussein Intersection and 57 for Bab- Al Mashhad at peak hours. Heat maps are showed the EB of the Bab Al Hussein Intersection is the highest severity of conflicts, while the WB of the Bab Al Mashhad Intersection is the least severity of conflicts.

Queue length has a double effect on safety, it increases the frequency of conflicts at the same time reducing the severity of conflicts, so conflicts increase with increase queue length, where predictive models showed that an increase in queue length by 10% leads to an increase in the frequency of conflicts by 20%. TTC values for 40 St. and Bab-Al Hussein Intersections were (0.86,0.82), respectively, so both were classified as high-risk intersections.

A virtual simulation of the countermeasures has been made for 40 St. and Bab-Al Hussein intersections, and through these countermeasures, the results showed possible to decrease risk at those intersections from high risk to moderate risk. by changing some geometric characteristics, while Bab Al-Mashhad intersection TTC value of (1.23), was classified as a moderate-risk intersection.

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List of Acronyms

Symbol	Details
AASHTO	American Association of State Highway and Transportation Officials
CC	Crossing Conflict
CSO	Central Statistical Organization
DGML	Detroit General Motors Laboratory
DR	Deceleration Rate
EB	Eastbound
FHWA	Federal Highway Administration
GIS	Geographic Information System
HCF	Hourly Conflict Frequency
HCM	Highway Capacity Manual
HR	High Risk
HSM	Highway Safety Manual
HTC_{APP}	Hourly Traffic Conflicts at Approach
LCC	Lane-Change Conflict
LOS	Level of Service
LR	Low Risk
MAPE	Mean Absolute Percentage Error
MLOS	Multimodal Level of Service
MOEs	Measure of Effective
MR	Moderate Risk
NB	Northbound
NHTSA	National Highway Traffic Safety Administration
OPM	Operation Performance Measure
PCC	Pearson Correlation Coefficient
PET	Post Encroachment Time
PTV	Planung Transport Verkehr (German Language)

REC	Rear-End Conflict
ROC	Risk of Collision
SB	Southbound
SPM	Safety Performance Measure
SPSS	Statistical Package for the Social Sciences
SSAM	Surrogate Safety Assessment Model
TCT	Traffic Conflict Technique
THTC	Total Hourly Traffic Conflict
TIT	Time – Integrated Time
Trj.	Trajectory
TTC	Time-To-Collision
US DOT	United State Department of Transportation
VISSIM	Verkehr In Städten – Simulationsmodell (German Language)
WB	Westbound
WHO	World Health Organization.

CHAPTER ONE

Chapter One

Introduction

1.1 General

Traffic safety is a major transportation engineering aspect. According to World Health Organization (WHO), more than 1,350,000 people die every year due to crashes and more than 50 million people suffer from disabilities that may not improve. All efforts must be combined, especially traffic engineers, to prevent deaths resulting from crashes, of which part may be under our control.

The design, planning, and maintenance of transportation facilities must consider crashes' impact when designing or assessing alternative designs because crashes are the direct traffic safety measurement[1]. In case of lack of crash data, searching for a surrogate measure to evaluate the safety status would give traffic engineers a clear vision of safety in the present and the future.

Researchers are studying alternative methods, and one of these methods is the simulation method to determine road safety and find treatment for the lack of safety by simulating countermeasures. The simulation method was resorted because of the weakness of traditional methods due to poor data and at other times because of the mood of the observers[2][3].

For testing the safety levels of existing and modern infrastructures, the simulation method can be considered a promising approach coupled with the software developed by Federal Highway Administration (FHWA), Surrogate Safety Assessment Model (SSAM), which automates the analysis of conflicts by analyzing the vehicle trajectories generated by simulation, that considers the core of this strategy[4][5][6].

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1. 2 Traffic Safety In Iraq, Facts & Numbers

Wars and terrorism are not the only these harvesting Iraqi lives. Traffic crashes in Iraq have become one of the biggest daily fears that threaten the citizens' lives after the violent works and deadly diseases that killed Iraqis after 2003[7].

Iraq is witnessing a large number of traffic crashes and the fall of large numbers of deaths and injuries, which have reached high numbers over the past ten years. This is confirmed by the annual reports issued by the Iraqi Ministry of Planning / Central Statistical Organization (CSO) and in coordination with the Ministry of Interior / Criminal Statistics Directorate. The following are the main indicators of traffic safety for the year 2019, according to (CSO) Iraq, in all governorates except the Kurdistan region[7].

❑ **In Iraq**

- The number of traffic crashes recorded was (10753), of which (2629) were fatal crashes and non-fatal crashes were (8124) in 2019 [7].

- Crash collisions recorded the highest percentage with (52.7%) of the total crashes in 2019 [7].

❑ **In Hilla City**

- Numerical statistics of crashes, injuries, and deaths for the period from 2014 - 2019 are shown in Figure (1-1) [7].

- The percentage of deaths (18.5%) and injuries (81.5%) were recorded from 2014 until 2019. As shown in Figure(1-2) [7].

- The number of traffic crashes in Hilla city reached 329 from 1127 crashes in Babil Governorate, which were distributed to five districts. Figure (1-3) shows crashes number of each district[7].
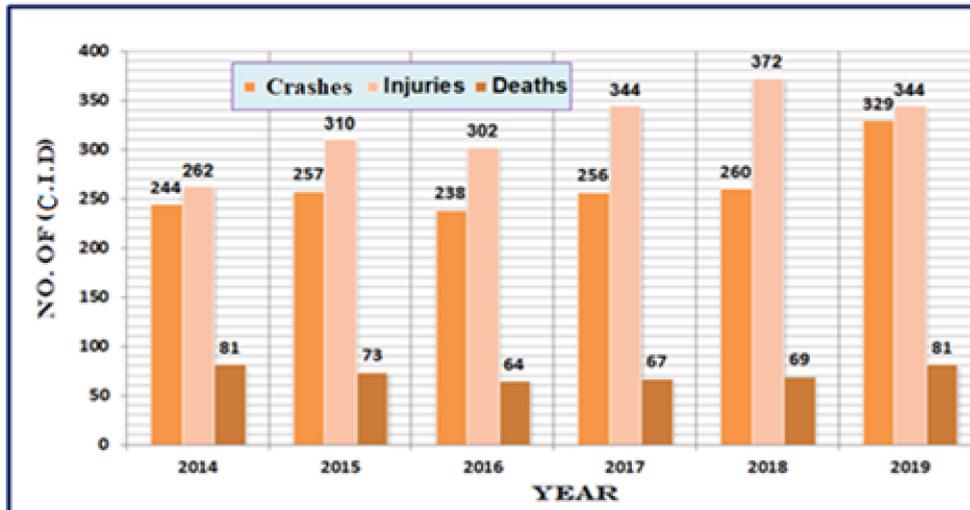
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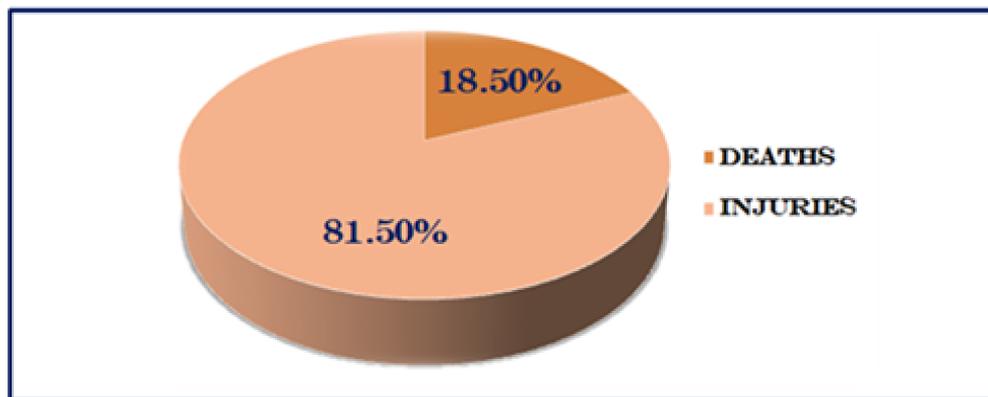
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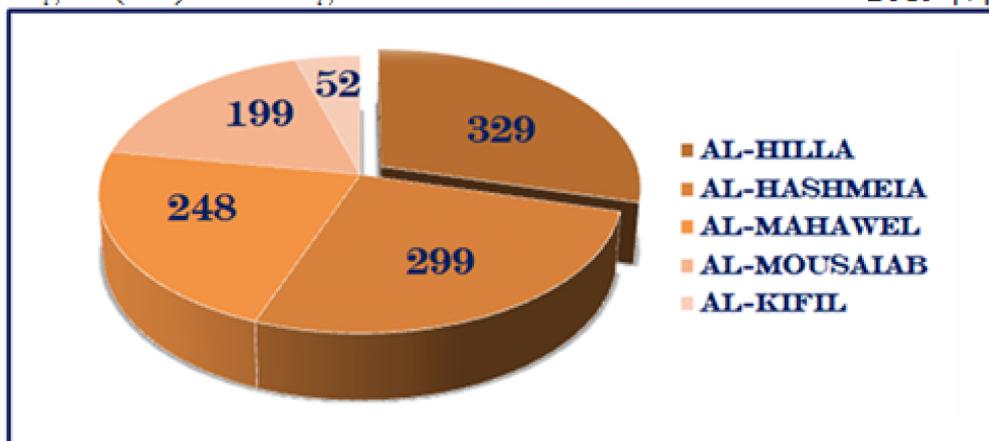
Figure (1-3) Crashes Number in Each District at Babil Governorate 2019 [7]

More details are in Appendix A. The statistics indicate high rates of crashes that require reducing their occurrence. One way to reduce it is to take an optimal approach based on an efficient assessment of the traffic safety situation.

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1.3 Simulation Concept and Advantages

Simulation has many concepts or definitions, but it leads to one goal. One of these definitions is a viable surrogate measure to studying different transportation issues by designing a model of the real world for understanding, evaluating, and solving complex problems related to traffic matter such as congestion, delay, travel time, and safety[8]

Nowadays, Simulation has become an inevitable tool for analyzing, interpreting, and displaying real-world traffic engineering situations[9]. Following are some advantages of simulation tools.

- Ability to simulate complex vehicle interactions and very large traffic networks, flexibly.
- Eliminate the weaknesses of traditional methods
- Simulation achieves great flexibility in the use of time.
- Less expensive and less risk to workers
- Future projects can be simulated and alternative projects can be compared.

1.4 FAHW's Vision for Safety

Safety is a primary concern in most parts of the world. The United State Department of Transportation (US DOT), represented by FHWA, is working to implement an integrated program of studies, innovations, infrastructure maintenance, calling to be taken for innovative safety countermeasures, and others with the goal reduce deaths and injuries associated with the transportation system.

For this reason, FHWA fully supports zero vision (prevent fatalities and injuries on its roads)[10]. It strives toward zero, the only acceptable number for safety deficiency.

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1.5 Problem Statement

Lack of traffic safety causes the danger of wasting and depleting the human and financial resources resulting from traffic crashes. Despite several factors that affected safety, such as the entry of large numbers of imported vehicles and demand on the transport network and trade openness after 2003. But have not taken sufficient attention from the central and local governments.

Moreover, with no crash data assigned to specific sites (intersections or road segments), there is no way to estimate or measure safety for a site or facility. Even with an available systemic way to collect crash data for sites, still should wait at least 3 years in order to apply traditional methods.

1.6 Aim and Objectives of the study

The primary objectives of this thesis are:

- Determining if SSAM and VISSIM can provide a reasonable estimation for traffic conflicts at the signalized intersections.

- Determine the optimum thresholds for the two main safety indicators Time To Collision (TTC) and Post Encroachment Time (PET) and classification the intersections from the term severity risk (low, moderate, and high) risk.

- Identification number of conflicts and the predominant conflict type in each approach and entire intersection.

- Showing the densest and dangerous places through SSAM's maps and Arc-GIS.

- Finding the correlation between the simulation and the field approach, developing models to predict the number of conflicts based on traffic volumes and queue length.

- Conducting a proactive examination as a countermeasure to improve safety at study sites.

1.7 Thesis Structure

The thesis involved five chapters. The first provides a brief description of the current state of traffic safety in Iraq and Hilla city, basic definitions used in safety, simulation concept and Justification for their use, and shows problem statement and objectives for thesis.

Chapter two consists of a review of related literature, describing surrogate safety measures, traffic conflict techniques, and microscopic simulation. Provide an overview of SSAM and VISSIM Software.

Chapter three deals with conflict, geometric, crash, calibration, and traffic data collection and briefly presents the VISSIM methodology.

Chapter four included an SSAM analysis of the trj files created within the simulation model. The number, type, and severity of conflicts were obtained, as well as calibration and verification of the simulation model, assessing the severity of intersections, and conducting a proactive examination to improve safety at intersections.

Finally, Chapter five concludes this thesis by providing summaries of the major findings of the research, summarizes the major recommendations to better enhance safety. and highlights future studies to treat cases that are not mentioned in this study.

CHAPTER TWO

CHAPTER TWO
LITERATURE REVIEW

2.1 General

The high rate of intersections crashes provides a keen justification to work in order to develop efficient and objective guidelines for improving traffic safety [11]. Intersections safety is of a national and local primacy in a transportation system. According to this vision, organizations, and Institutes such as (FHWA, National Highway Traffic Safety Administration NHTSA, the Institute of Transportation Engineers ITE, and other private organizations) seek to continue to find efficient solutions to make intersections safer.

At the same time, the specialists realized that there is an urgent need for simulation to optimize and forecast network behavior at different traffic characteristics. As well as conducting many scenarios that provide an overall understanding of the traffic and chance to immediately evaluate adequately and securely [12].

2.2 Historical Look of the Term Traffic Conflict

The meaning of a risky interaction is defined by De Silva[13]. Though the term traffic conflict was employed for risky interactions via Klebelsberg [14], its first implementation to describing safety-regarding issues is attributed to the Detroit General Motors Laboratory (DGML) [15]

In that period, the concept was comparatively broad than today because included traffic violations. Hayward [16] restricted the concept of traffic conflict involved that required change direction or speed to avoid a collision. In 1977, an official definition of traffic conflicts was given at workshops held in Oslo[17].

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Many researchers in the US and Europe have engaged in developing traffic conflicts concept, including producing standard criteria (Hauer [18], Horst [19], Hydén [20]; van der Horst & Kraay [21], Sayed & Zein [22],....etc.). Other researchers attempted to improve the concept through revisiting the conflict's proximity to collision.

Some others were suggested measuring traffic conflicts without the need for human observers, this was crowned in the use of a new approach represented by simulating traffic conflicts. The idea dates back to Archer [23]. Several studies have been conducted to elicit conflicts from the simulation to this day as shown in next section.

2.3 Previous Studies of Traffic Conflict

Fan et al [24] used VISSIM and SSAM software to estimate traffic conflicts by field measure at freeway merge zones. The conflicts in the field-collected manually, and conflicts have been compared with simulated conflicts. The outcomes showed a sensible consistency between the observed conflicts and the simulated.

Vasconcelos et al [25] the researchers' goal was to verify the SSAM and the simulation model as tools to predict crashes at urban intersections, two validation methods were used. The first method involved comparing the number of conflicts simulated by VISSIM and analyzed by SSAM and the expected number of crashes extracted from the analytical models in three sites (four leg priority intersection, single-lane roundabout, and four legs staggered intersection).

Muley et al. [26] use the micro-simulation environment to predict the conflict between a vehicle and another vehicle, as well as between vehicles and pedestrians conflicts at Doha signalized intersections in Qatar's country. The studied intersections are modeled by the VISSIM

simulation tool, where vehicles and pedestrian trajectories were created. Then (SSAM) was used to analyze the simulated to identify conflicts within the study zones.

R. Majeed & H. Ewadh [3] studied traffic safety assessment at nine signalized intersections in Baghdad city in two ways. The first was based on Highway Safety Manual using three methods (Empirical Bayes, crash rate, and crash frequency). While (conflicts rate and conflicts frequency) were applied in a second was based on conflict. The study showed that the dangerous conflict frequency in conflict-based methods is perfect than the crash frequency method. So, the dangerous conflict frequency maybe serve as an applicable option for safety performance evaluation.

Guo et al [27] investigated the relationship between field-measured and simulated conflicts, estimated from the (SSAM) for two signalized intersections in Brisbane city of Australia. The study results indicated a good connection between field-measured and simulated conflicts, particularly at the higher for (TTC) thresholds.

The results displayed that conflict could be reasonably surmised. Further, the micro-simulation approach can be used to foresee potential conflicts during scenario testing, and the outcomes can be identified to assess the effect of the geometric improvement in decreasing the potential conflicts.

Cruz et al [28] presented their paper that includes a study of traffic safety in two roundabouts using a simulation approach. This paper shows the results of a comparative safety assessment between the proposed basic turbo-roundabout and existent two-lane roundabout, they're designed for the same intersection, to define the best of the two from a safety perspective, depending on surrogate safety measures and traffic conflict

through the micro-simulation model (VISSIM) and SSAM software to identify six surrogate measures. The number of conflicts was found (72%) fewer at the turbo-roundabout and found that traffic conflict at the turbo-roundabout in a form cluster group, while conflict at the roundabout is scattered.

Molan et al [29] studied safety assessment by using the VISSIM simulation model and the surrogate safety assessment model SSAM at new Offset Diamond Interchange (ODI) instead of the traditional interchange due to its failure. Based on the results, the(ODI) showed the possibility to be a successful alternative and favorable design in the terms of safety.

Whereas the second method involved comparing SSAM's results with the conflicts observed in the field at four intersections, two of which were roundabouts. Their research paper indicated though that there are some restrictions related to micro-simulation models, SSAM analysis is a considerably favorable approach to reach a proper assessment of new traffic facilities or future layouts.

2.4 The Concept of Safety Pyramid

In 1987 Hyden proposed the concept of a safety pyramid or it is sometimes called the Hyden pyramid, which comprises different levels for all the possible interaction events that are inevitably created within any vehicular flow. Hyden presumed that the form of the severity hierarchy is a three-sided pyramid, the intensity which was ranged between the base and the top as shown in Figure (2-1). This Figure illustrates the connection between the severity of the event and the probability that it will occur and indicates the most probable events are less serious ones, while less probable events are the most serious[30]. According to this approach, the hierarchy of safety was divided into three parts, as shown below:

- **Pyramid Base**:- represents safe traffic events and vehicle interactions undisturbed.

- **Pyramid Middle:-** conflicts may exceed the potential of occurrence and sometimes surpass even the slight conflicts to be severe.

- **Pyramid Top:-** represent dangerous events and the severity ranges from damage to injuries and it may be fatal in some cases.
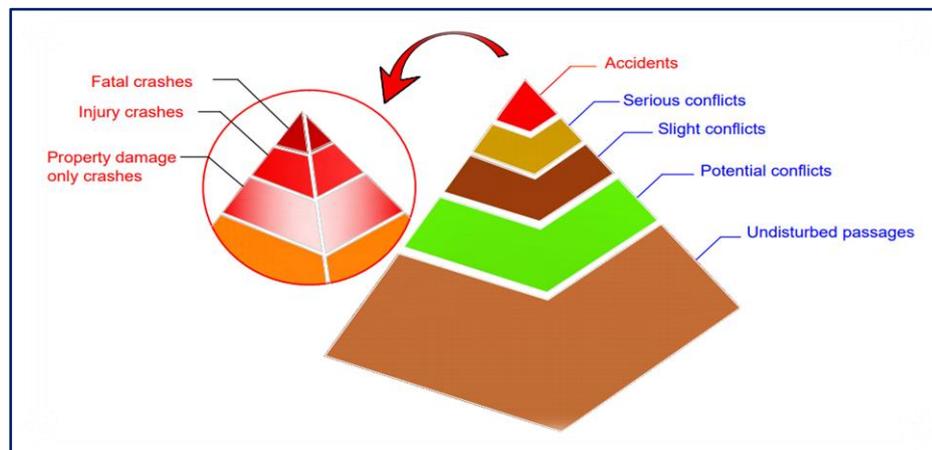
Figure (2-1) Hyden's Safety Pyramid[30]

2.5 Safety Indicators, Temporal Proximity

Measures of proximity play an essential role in Traffic Conflict Technique (TCT's) and simulation approaches, however, there are still matters associated with these events. The first is that although there are many traffic conflict measures, no full agreement has been reached on what measures should be applied [31].

The reason might be various measures are different in nature and have their desirable application situations. Researchers developed many proximity measures and Non-temporal Proximity indicators. The surrogate indicators based on temporal proximity represented the most popular measures because they integrate both spatial proximity and speed. The proximity in time and (or) space provides a quantitative way to distinguish

critical events from other events. Time-To-Collision (TTC) and Post-Encroachment Time (PET) are representing the most common temporal proximity indicator family [32].

On the other hand, SSAM's safety analysis model entirely relies on only these indicators in the safety analysis and evaluation. The rest of the indicators of time proximity and non -temporal proximity are in appendix B Table (B-2), presenting a brief description of some of them used in the studies for measuring and evaluating traffic safety.

2.5.1 Time-To-Collision (TTC)

In 1971 Hayward,[16] used TTC and defined it as the expected time to occurrence collision between two vehicles if both vehicles stay in the same direction and maintain their speed unchanged. as shown in Figure (2-2).
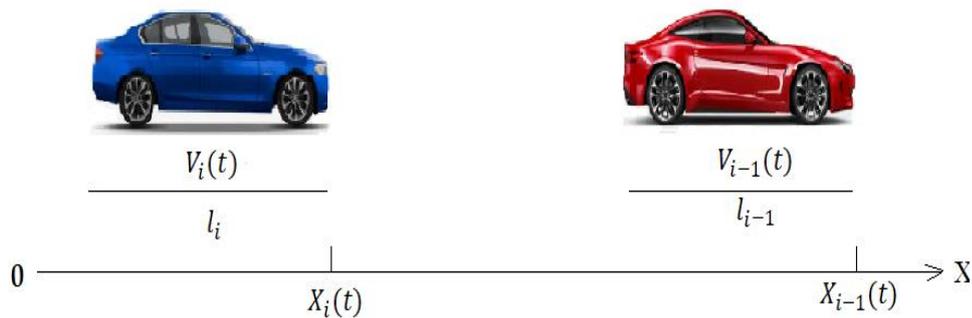
Figure (2-2) TTC Concept [16].

$$TTC_i(t) = \frac{X_{i-1}(t) - X_i(t) - l_{i-1}}{V_i(t) - V_{i-1}(t)} \qquad (2.1)$$

Where:

$TTC_i(t)$=Time To Collision between two consecutive vehicles at any time t.

$((X_i(t)$ **and** $V_i(t))$= Position and velocity of the following vehicle i respectively at any time t.

$((X_{i-1}(t) \text{ and } V_{i-1}(t))$= Position and velocity of the leading vehicle i respectively at any time t.

$(l_i \text{ and } l_{i-1})$= Length of the following and leading vehicle i respectively.

TTC varies according to studies, however, some studies applied multiple thresholds to identify the levels of severity for conflicts. The value of the threshold for TTC may be used as the default value 1.5 s by researchers as the most common value at intersections as a threshold for distinguishing between serious and non-serious conflict[33].

Table (2-1) presents the minimum and desirable TTC threshold values in some studies. But in the simulation approach is identified the value of TTC by the SSAM model is consider the first and important step to conducted and completed the analysis of trj files.

Table (2-1) Minimum and Desirable TTC Threshold Values [34]

Reference	Min. (Sec)	Desirable (Sec)	Condition
Van der Horst,1990	1.0	1.5	Approaches at Intersections
Sayed et al.,1994	1.6	2.0	At low level of traffic conflicts
	0	0.9	At high level of traffic conflicts
Sayed and Zein, 1999	1.0	1.0	Signalized and unsignlized intersections
Gettman et al, 2008	----	1.5	Signalized and unsignlized intersections
Huang et al., 2013	----	1.6	Signalized Intersections
Sayed et al.,2013	----	3.0	Signalized Intersections
El-Basyouny and Sayed, 2013	----	1.5	Signalized Intersections
Sacchi and Sayed , 2016	----	1.5	Signalized Intersections

The theoretical TTC curve debated by Hayward is shown in Figure (2-3). When the road user acquires a collision course the curve starts until reaches some minimum value (in case of a collision this value is equal to zero) Johnsson et al [34] when the collision course stops existing, the curve "jumps" into infinity.
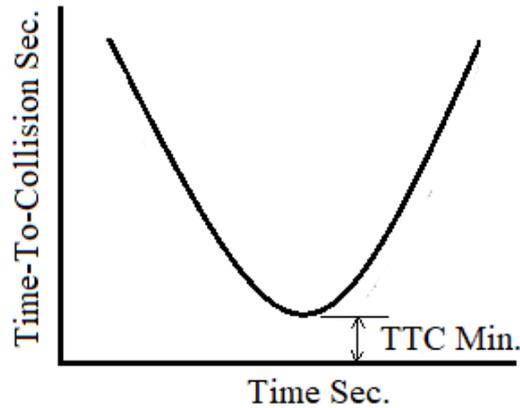
Figure (2-3) Theoretical TTC Curve [32]

2.5.2 Post-Encroachment Time (PET)

Post-Encroachment Time ʻPETʻ is a second time-depend surrogate indicator. PET was implemented in 1978 by Allen et al. [35] PET is defined as the time difference between the first vehicle passing at the intersection point to the moment that which the second vehicle passes at the same point, Figure (2-4) illustrates this meaning. This indicator was widely utilized [36][37].

$$PET = t_2 - t_1$$
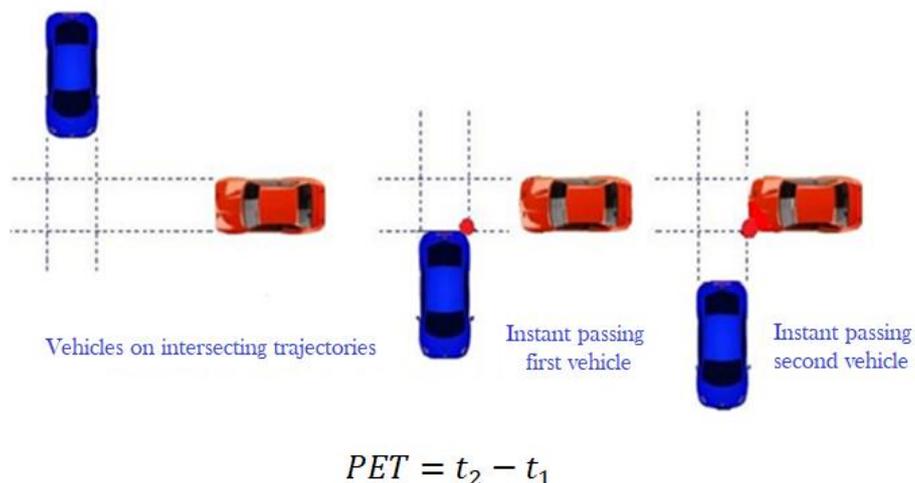
Figure (2-4) PET Concept [35]

PET is useful for evaluating the safety level of unsignalized intersections under different traffic volume and speed limits, since the use of the PET is only for investigating crossing collisions, other safety indicators such as TTC coupling with PET are also necessary for analyzing other types of collisions, such as rear-end and lane-change collisions.

PET works best in analyzing conflict crossing for it demands a specific conflict point to be picked from dealing with the rear-end and lane-change conflicts[23]. The relatively large number of studies that have used PET has allowed an analysis of PET values when those values are used to classify between serious and non-serious events. In Figure (2-5), notice that the use of predetermined PET[38] values is less common than in studies using a predetermined TTC_{min} value. Very few publications used predetermined PET values in their publications to distinguish between serious and non-serious events, which is noticeably contrasting to $TTC_{min.}$
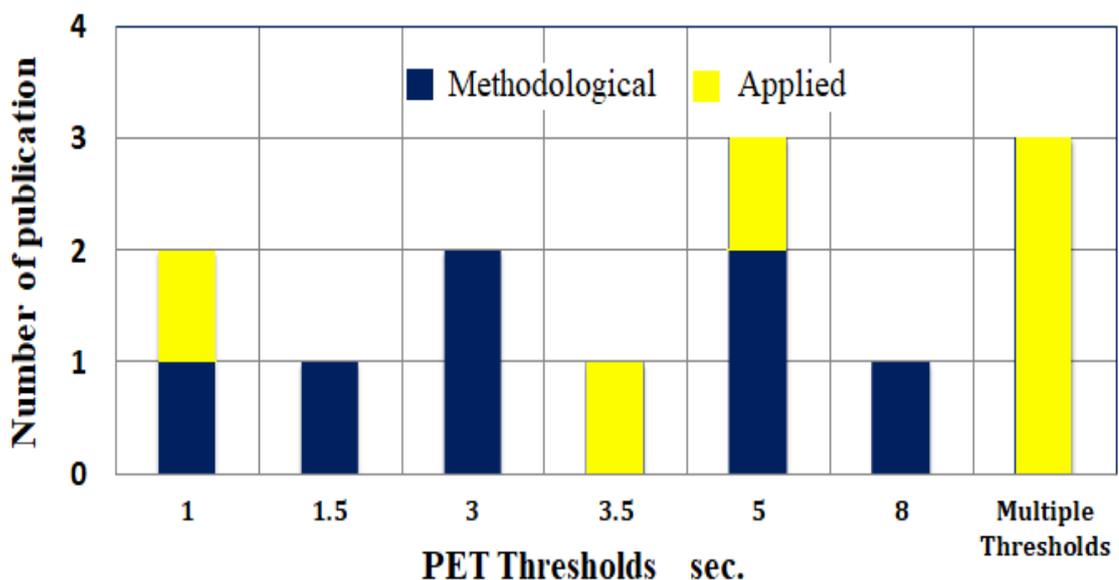
Figure (2-5) Number of Publications Adopted on Predetermined PET Values [39]

(PET) was validated to a certain degree by a number of studies with totally several methods Sonchitruksa & Tarko [40]. A study by (Alhajyaseen,) [41]validated a conflict index extracted from a set of crash probabilities that elicited from PET.

With regard to the simulation-based approach, both TTC and PET values are very important and are determined by the SSAM model and do not rely on the values of previous studies because they are the backbone of conflict analysis. After creating the trajectory file with a micro-simulation VISSIM and exporting the file to SSAM. SSAM analyzes the file, The first step in SSAM's analysis is to find the optimal values of both TTC and PET for each intersection separately.

2.6 Surrogate Safety Measures

The concept of alternative safety measures refers to measures other than crashes records, that are important to meet the following requirements[42]:

- There is an urgent need to evaluate safety in traffic facilities without staying long to obtain more crashes so that they are valid and statistically significant.

- There is an urgent need for the ability to evaluate the safety, experiential operational strategies, and/or roadway designs before they are actually constructed or used in the field.

Several studies hypothesized the use of several surrogate safety measures more detail of them in the Table (B-2) Appendix B. The most spread works of literature in surrogate measures are regarding traffic conflicts technique, which is concentrated on monitoring traffic conflicts. In this study, surrogate safety measures were derived from a simulation approach and specifically from the SSAM model.

2.7 Micro-Simulation Technique

Micro-simulation has been a widely applied technique in many fields of transportation[43]. A cautiously modeled and well-calibrated micro-simulation model grants its users the ability to emulate real-world traffic operations by applying the micro-simulation technique; researchers can overcome defects of measures of safety and can often estimate the effect of a proposed infrastructure treatment before actually undertaking the treatment. As a result, The micro-simulation model can be incredibly powerful in many analyses. The micro-simulation technique can be regarded as a potent alternative for traditional studies[44].

In the past, most literature has devoted efforts to developing micro-simulation models to evaluate directly quantifiable norms such as flows, speed, queues, and others. Recently, researchers have been motivated to explore the potentials of using the micro-simulation technique for evaluating traffic safety, which is more difficult to quantify directly Gettman & Head [45]. In addition to the use of TTC and PET thresholds as indicators of traffic conflicts, other indicators, such as maximum speed (Max S), speed differential (Delta S), and initial Deceleration Rate (DR), were also presented by (Gettman and Head)[45].

Former studies such as Mehmood et al.[46] provided essential insights into used micro-simulation-based methods with regard to modeling relationships among highway traffic flow changeable, geometric characteristics, and highway safety. Since the development of SSAM, researchers have devoted more efforts to using micro-simulation to study traffic safety. The main advantage of using micro-simulation models is a proactive tool to measure and evaluate the traffic safety condition but not free?. In addition, the simulations need the SSAM surrogate safety assessment model that is owned by the US Department of Transportation to

analyze the simulation files from a safety view, which is also difficult software to obtain. Before addressing SSAM's methodology for analyzing and classifying the type and severity of conflicts to assess safety, it is necessary to know the foundation/godfather of the SSAM model, which is the (Planung Transport Verkehr-in German Language) PTV VISSIM simulation model where many researchers used the micro-simulation VISSIM to evaluate safety at different traffic facilities where the [47][25][48].

2.8 PTV VISSIM

Cities around the world are studying how digitization can improve traffic flow. PTV VISSIM is one of the most famous digitization and used across the globe simulation software to evaluate traffic problems such as safety, delay, emissions, etc. PTV VISSIM allows with simulating different modes of transport, and pedestrians, it is owned by PTV Group.

VISSIM simulation platform was used in this study to simulate the traffic interaction at signalized intersection locations. The main advantages of VISSIM other contemporary software are:

- Flexibility in dealing with interactions between two vehicles in the same lane, lateral movement of vehicles, and gap acceptance controls (Habtemichael and Picado)[49].
- Allows calibration of different parameters that include the driver's behavior to reach real traffic situations.
- VISSIM has many routing decisions for vehicles, allowing many scenarios.

Thus, companies and cities save money and time, enhance road safety and reduce the impact on the environment with VISSIM. So VISSIM is a valuable and effective tool for transportation engineering[50].

2.8.1 VISSIM Concept for Safety

In contrast to models that characteristics with a less complex that used a constant speed, VISSIM utilizes the physical-psycho driver behavior model develops by Wiedemann[51]. VISSIM characterize by capturing driver decisions and reactions in different traffic situations, and a time step of 0.1 seconds provides a high resolution of vehicle trajectories[51], which provides detailed vehicle interactions. The traffic safety measurement in this software depending on the vehicle's longitudinal movement and the lane-change algorithms for lateral-vehicle movements.

The main notion of the VISSIM model is when driver reach realizes there is a vehicle in front of him that is moving slowly, and due to his inability to determine its speed, he begins to decelerate from his speed to reach a deceleration that achieves a speed less than the speed of the vehicle ahead of him or trying to change his course if possible, pending he begins a little accelerated another once after arriving at another perception threshold. The repetition of these thresholds occurs as a result of the difference in road, position, and speed. VISSIM simulation model depends internally on three various parts:

- Traffic flow model
- Traffic control (signal light) model
- Data analysis package

VISSIM assume that driver can be in one style of four driving behavior[52] as fallowing:

- **Free drive:** No effect of preceding vehicles observable (physical obstacles is not existing downstream)

- **Following:** The driver chases the preceding vehicle without accelerating or decelerating while maintaining a safe distance where the speed difference between them is centered around zero.

- **Approaching:** Driver's behavior in fitting his speed with the slow speed of vehicle a preceding while approaching it.

- **Braking:** The application of medium to high deceleration rates if the distance decreases than the required safety distance.

VISSIM adopts Weidmann's model of driving situations. Figure (2-6) shows the stages of driving from free driving until the collision stage.
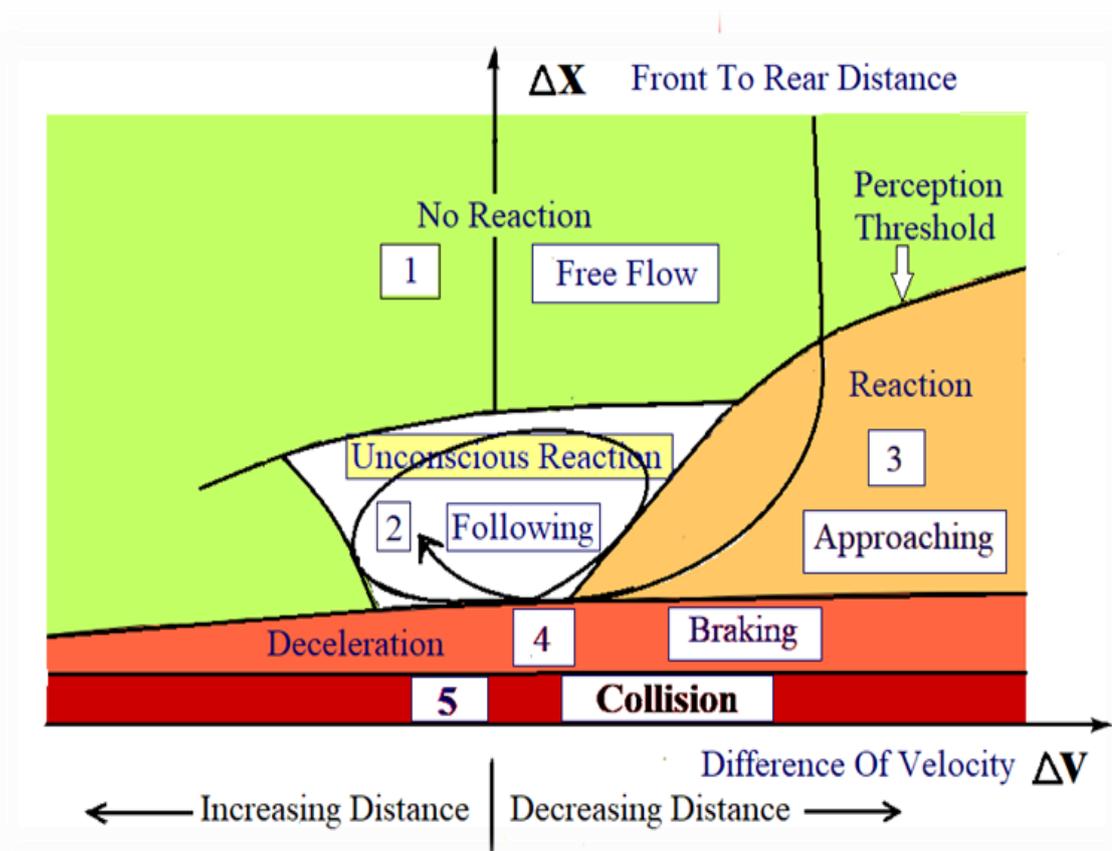
Figure (2-6) Driving Logic According to Wiedemann [51]

2.8.2 VISSIM Calibration

Initially, to calibrate the VISSIM traffic simulation model, the researchers used the principle of trial and error in calibrating the model, they often used the default parameters of the simulation software to represent different traffic scenarios, and this led to many mistakes in the simulation results, as reported by (Schneeberger and Park) [53].

Traffic simulation models include different default parameters, including driver behavior parameters, which are the main component of any traffic simulation. Driver's behavior illustrates how vehicle drivers make their decisions about safety distance, lane choice, and other driving decisions. The drivers' behavior differs greatly from geographical location to another, therefore, these default values seldom match the domestic traffic characteristics and conditions of traffic for a specific zone[54]. Thus, the default parameter values should be modified to obtain a simulation that represents the study sites in proper.

While some researchers such as (Sayed and Essa) [55], have shown the possibility of transferring calibrated driving behavior parameters from one region to another with the same characteristics, but in different societies, the parameters of driving behavior are strongly influenced by the social and the cultural background and geographical position. (Asmer et al.) [56] suggested the following parameters for calibration like clearance distance, adjacent lanes distance, and standstill distance. However, these parameters do not equally impact on calibration. Calibration conduct is not easy and direct, therefore, It is essential to determine Measure of Effective (MOEs) before proceeding further for conducting the calibration. The literature concluded that simulation models should be rigorously calibrated, and some of them are summarized in Table (2-2).

Table (2-2) A Summary of Some Studies Relating with VISSIM Model Calibration

Author(s)	Facility Type	Calibration Parameters	Finding
W. Zhizhou et al. [57]	Expressway China.	Reduced Speed Area DSRSA, Desired Lane Change Distance DLCD .etc	Generally, Many simulation experiences indicate the main parameters have an impact on result precision most deeply the calibrated parameters estimation refer that drivers in Shanghai are more truculent in lane-changing and car-following compared with the default values in VISSIM model.
Flavio Cunto and Frank F. Saccomanno [47]	Signalized Intersection USA	Desired deceleration, Safety distance, reduction factor, Observed vehicles ahead, .etc	Calibrated concluded, two possible improvements to this study are 1-combining observational data from different provenances to improve the transferability of the results of the calibration (i.e. roundabouts, freeway sections intersections, and stop-controlled) 2- establishing a statistical model is able to replicate safety performance as in rear-end crash.
Rong Fan et al [24]	seven freeway merge areas China.	Min gap time, Safety Distance Reduction Factor, etc.	The results showed that the two-stage calibration procedure greatly improved the consistency between the observed and simulated discrepancies and this was reflected by the Spearman correlation coefficient between the two survivors, where the MAPE values for the total conflicts were reduced from 71 to 19.9%
D. Espejel-Garcia, et al. [54]	Expressway Chihuahua City, Mexico	Additive part of safety distance. average standstill distance, etc.	The values of the calibrated VISSIM parameters were found to be less than the default values and were validated by forward-looking distances as well as travel times. Calibration was performed by two methods of genetic algorithm and manual
Yanyong Guo et al. [2]	Signalized Intersection Canada	Standstill distance, headway time, desired deceleration,. .etc	EVT-based titration improved the estimation of safety measures, and this was reversed by lower values for MAPE. Calibration method has outperformed the method of Essa and Sayed [58]in terms of safety predictions, and this was noted in estimating collision frequency.

2.9 SSAM Model

Traffic safety assessment has always been a major concern for those interested in this matter due to the poor methods used in safety assessment, therefore, motivated by the necessity to more efficiently assess traffic facilities, which required a new approach to the use of surrogate safety measures, i.e. Safety measures that do not depend on a series actual crash (historical crash records) [59].

A software tool has been provided by the (FHWA) for this purpose, called the Surrogate Safety Assessment Model (SSAM). SSAM is else method that utilizes surrogate safety measures to evaluate safety. SSAM performs an analysis operation of the trajectories files produced by the simulation model VISSIM

2.9.1 SSAM Advantages

- SSAM eliminates subjectivity related to the conventional conflict analysis methods[25][60].

- Provides flexible safety analysis through its tools and displays comprehensive information on each conflict[61].

- Compatible with four traffic simulation models (VISSIM, TEXAS AIMSUN, and PARAMICS)[43][60].

- SSAM is consuming less time for safety analysis when compared to other traditional methods[61].

2.9.2 SSAM Work Concept

The simulation model creates a trj file that contains the interaction of vehicles (more details of creating a trj. file in Chapter 3 VISSIM methodology). VISSIM's inability to analyze conflicts, which requires a program that analyzes these interactions.

SSAM implement this by analyzing the data within the trajectory file and examining the interactions between the vehicles, whether they can be considered conflicts or not. SSAM calculates surrogate safety measures for each conflict between a pair of conflicting vehicles and offers a statistical summary of these measures[45].

SSAM takes a series of steps to analyze these files (steps are mentioned in Chapter 4 Data Analysis) to obtain the number, type, and severity of conflicts based on the optimal thresholds for the two main safety indicators TTC and PET. Figure (2-7) briefly shows the simulation of the trajectory files generated from field data and exporting those files to the SSAM model to analyze and evaluate safety results.
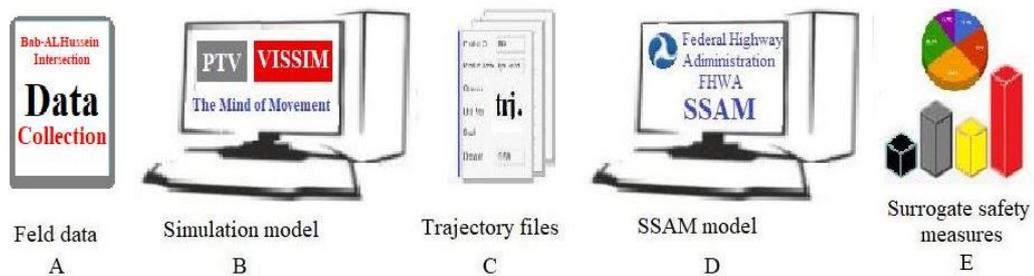
Figure (2-7) SSAM Workflow [62]

2.9.3 Surrogate Safety Measures, Calculated by SSAM

SAAM records and calculates the surrogate safety indicators for each conflict based on vehicles interactions analysis (Getman, Pu, Syed, & Shelby)[62]. This data is supplied in the table of conflicts in SSAM

outputs. By applying different filters to the simulation, outputs representing (trajectories) contributed to identifying the number, type, and severity of conflicts. Figure (2-8) shows A space-time diagram for surrogate safety measures calculated by the SSAM model.

In Figure(2-8), the trajectories of the through and crossing vehicles were symbolized by curve (A) and curve (B), respectively. In such a case, the value of TTC can be calculated (Gettman and Head, 2003a,b)[45][59] TTC = (t4 − t3) where, t3 (The time at which the corners of the crossing vehicle leave the encroachment point), while t4 (The time when the vehicle's through is expected to reach the point of conflict).

SSAM utilizes a unique algorithm to determine conflicts events, therefore, defines other parameters are described in Table (2-3) regarding each conflict. In our analysis were utilized a precision of 10 simulations per second to estimate these parameters every tenth of a second.
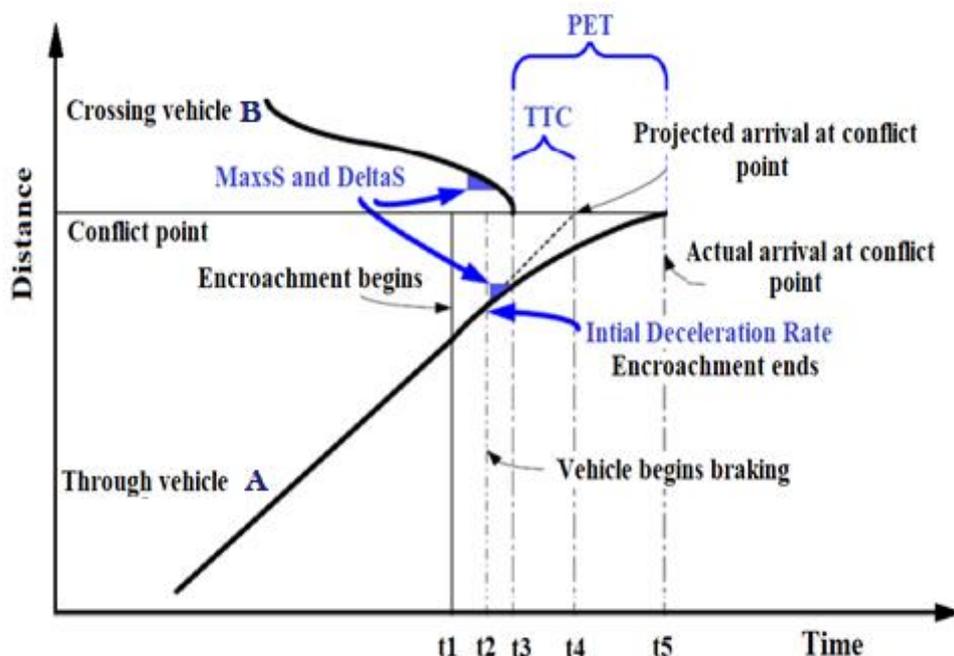
Figure (2-8) Conflict Point Diagram-Surrogate Measures [59]

Table (2-3) Description for Surrogate Safety Measures Calculated by SSAM [59]

Surrogate Conflict Measure	Description*
Time-To-Collision (TTC)	(TTC) is the Min. of Time-to-collision value observed throughout the conflict. This value depends on the immediate location, speed, and futurity trajectory for two conflict vehicles at a specific instant. TTC values are recorded for each time step through the events of the conflict in second-unit and It progresses by adding 0.1 s for each time step until it reaches the specified threshold of TTC. Zero value refers to actual collision.
Post-Encroachment Time (PET)	(PET) is the Min. of post encroachment time value observed throughout the conflict in second-unit when the first vehicle occupied a location and the following vehicle arrived at the same point, it progresses by adding 0.1 s for each time step until it reaches the specified threshold of PET.
Maximum Speed (Max S)	(Max S) is a maximum speed for one of the two vehicles throughout a conflict event. Its value is expressed according to the unit used in the trj file m/s or ft/s.
Deceleration Rate (DR)	(DR) is the initial deceleration rate for the following vehicle, these values are recorded as the immediate rate. If the vehicle applied brakes, this considers as the first value for a negative acceleration observed through the conflict. While in case the vehicle does not apply the brake, this considers the lowest value of acceleration observed through the conflict. These values are expressed in (meters or feet) per second, According to the units fixed in the corresponding trj. file.

Continued

Difference in Speeds (Delta S)	(Delta S) is a difference in speed of the vehicle as observed at Min TTC. More exactly, In mathematically means the value of the difference in vehicle velocities (i.e. trajectories), If Va and Vb are the velocity vectors for each first and second vehicle respectively, then Delta S = |Va - Vb |. in case the same speeds for both vehicles, v. If they are traveling in the same direction, Delta S = (0 and ($\sqrt{2}$)V) If vehicles traveling (same direction perpendicular) respectively.
Maximum-Deceleration (MaxD)	(MaxD) is the maximum deceleration for the second vehicle. these values are recorded as the maximum immediate acceleration rate observed through the conflict. Negative value refers to deceleration (braking or freeing of the gas pedal). Positive value refers to that the vehicle's not decelerated throughout the conflict. This value is expressed in (meters or feet) per second
Maximum Difference in Conflict Velocity (MaxDeltaV)	(MaxDeltaV)is the maximum value of DeltaV value of each conflicting vehicle calculated from the change between velocity of conflict and velocity of the post collision . This value alternative for the severity of the conflict.

* Description from SSAM User Manual [63].

2.9.4 SSAM Validation

SSAM is a software tool that reads and interprets trj files created by simulation models and calculates surrogate safety measures. for the confidence of the SSAM model as an urban conflict/incident prediction tool, its results must be validated [25]. Ideally, SSAM validation is done against crash records. However, due to the rarity of crashes, getting enough data from one location is extremely difficult.

Federal Highway Administration, which owns the SSAM program, has made great efforts to validate the SSAM model, through a report that included 83 four-legged signalized intersections in urban areas(Gettman et al.). The validation report carried out describes an evaluation of the effectiveness of SSAM. The SSAM validation report issued by FHWA included three distinct efforts are [40]:

- Theoretical validation,
- Field Validation
- Sensitivity analysis.

Eleven theoretical validation tests were implemented, major purpose of validation was to identify the correlation between the surrogate SSAM method and crash prediction models from the previous literature. Summary of theoretical validation studies are illustrated, SSAM approach has promise, yet more work is still needed.

Field validation work was implemented to evaluate the prediction performance abilities of the SSAM approach with an actual crash in the USA. 83 signalized intersections four-leg was used in the field validation. All intersections were modeled in the VISSIM simulation solely while continuing to use the successive upgrades of the VISSIM to take advantage of the features added for each new version of the software.

The crash records were obtained from the insurance merit records and these records were manually processed to separate them by event type (crossing, lane change, rear end). A set of statistical tests was conducted on the data to determine the correlation between simulation approaches (from conflicts) and intersection crashes (from insurance records). Then tests were evaluated.

The results of the field validation showed that the surrogate measures (conflict frequency by maneuver type) extracted from simulation models were significantly correlated R^2 equal 0.68 with actual crash data from the field. Also, conflicts distribution leans more heavily towards less harmful conflict events (rear-end).

As for the third verification (sensitivity analysis) conducted by FHWA, the sensitivity analysis worked to supplement the field verification, it was conducted on five U.S intersections of the SSAM verification through the use of four different simulation models (VISSIM, AIMSUN, TEXAS, and PARAMICS). In general, the results showed that the intersections modeled in VISSIM were the lowest in terms of the number of conflicts, while those modeled in TEXAS were the highest frequency of conflicts, whilst ranging between AIMSUN and PARAMICS at TTC value (0.5,1.0,and1.5 s).

There were no strong differences between the models in terms of the average values of TTC, although the AIMSUN and PARAMICS models were slightly higher[42]. Table (2-4) shows a summary of the verification methods used in some previous literature for the surrogate safety assessment model (SSAM).

Table (2-4) Summary of Some Studies that Validated SSAM Model

Author(S)	Facility Type	Verification Approach	Finding
Fei Huang, et al. [64]	Signalized Intersections China	Field Observation	Results analysis demonstrated reasonable goodness-of-fit between observed and the simulated rear-end, also total conflicts. Four simple regression models have been developed to correlate the types (rear-end, crossing, lane-change, and total) of simulated conflicts against those derived from the field.
Vasconcelos, et al. [25]	Four-Leg Staggered Intersection &Roundabout Portugal	Two Approach 1- Predicted Number of Injury Crashes 2- Conflicts Observed	Validation based on (APMs) crash prediction models demonstrated a strong correlation between APMs from regression and conflicts calculated by SSAM.As for field validation for four types of intersections. results showed SSAM is able to identify the dangerous areas of each intersection and a quite promising approach to evaluating innovative layouts safety.
Usama Shahdah, et al. [65]	Signalized Intersections Canada	Observed Crashes	The study offered a statistical method to join observed crashes with simulated conflicts. This join can supply an observational foundation that records results of simulation in an equivalent (CMF)format. Furthermore, though the (53)locations used for the study be given reasonable results, more effort is necessary.
Mohammad Ghanim & Khaled Shaaban [48]	Signalized Intersections Doha	Field Observation	Outputs indicate are likenesses between the simulated and observed conflicts, though the simulation approach resorted to overestimate the risks of collision, particularly those which include pedestrians. also indicate SSAM approach is able to identify conflicts related to diverging and merging maneuvers.
Yanyong Guo, et al. [66]	Signalized Intersections Australia	Automated Video Analysis Records at Field	Comparison of the locative distribution between conflicts measured by SSAM based on VISSIM simulation and field observations indicates that the SSAM model has limited ability to capture the conflict location.

2.10 Field Observation of Traffic Conflicts

Observation of traffic conflicts can be conducted from traffic conditions at site or estimated by using the simulation model to simulate traffic conditions. Observation in the field includes on-site observations and observing conflicts from videos were collected at the survey sites. Field conflict observation was applied in many studies such as Migletz et al. [67], Nel[68], and Ewadh & Neham[69].

Further, several studies indicated that field observation-based traffic conflicts are more valid from the records crash approach[70][71]. On-site field observations used to be popular but have been rarely performed during the last decade. The use of video analysis tools has become popular as on-site observation methods of traffic conflict. As well, observations of conflicts situation directly from a video in the office (i.e. without human observers at the observation site) are quite common as well. Other methods to collect conflict data using micro-simulation models.

(Parker and Zegeer) [72] introduced categorized of intersection traffic conflicts by type of maneuver, as shown in Figure (2-9), there are twelve main types of conflict that occur between vehicles. Same-direction conflicts (SDC) represented the major traffic conflicts at signalized intersections and include four basic types: slow-vehicle, right turn, left-turn, and lane-change conflicts. SDC happens when the first vehicle slows and/or changes direction and places the following vehicles at risk of rear-end or other types of collision.
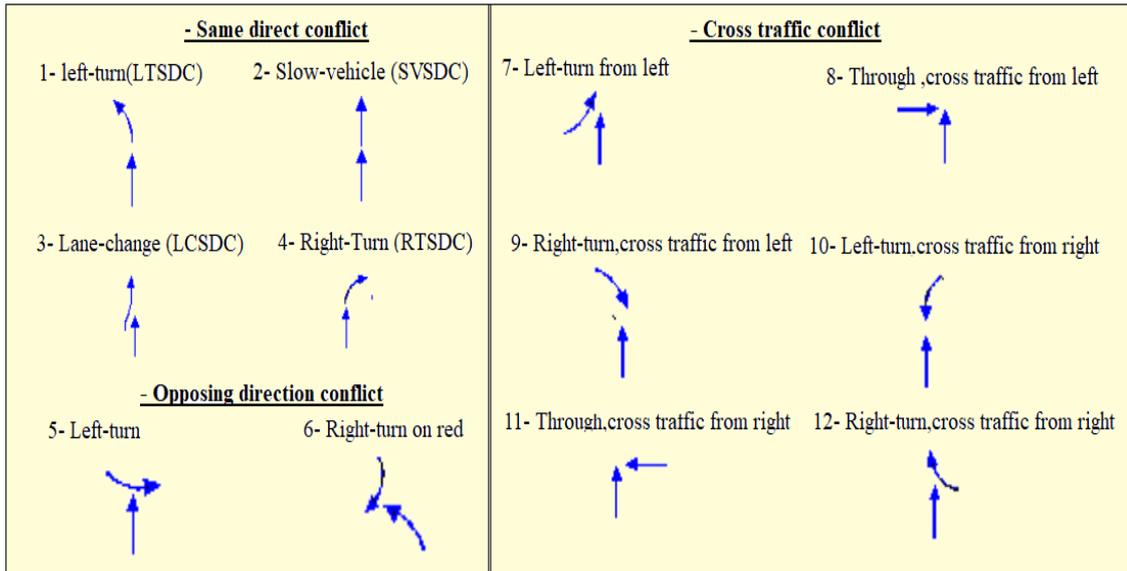
Figure (2-9) Conflict Types between Vehicles at Intersection [72]

The second vehicle makes evasive actions (such as brakes or swerves) to avoid the collision then continues to proceed through the intersection area. Whereas, the simulation-based approach classifies the conflicts into three main types based on the angle of conflict between each pair of conflicting vehicles as shown in Figure (2-10). If the angle (greater than 85, less than 30, and between 30 and 85) degrees. SSAM model classifies the conflicts into to (crossing, rear-end, and lane-change)[63] respectively.
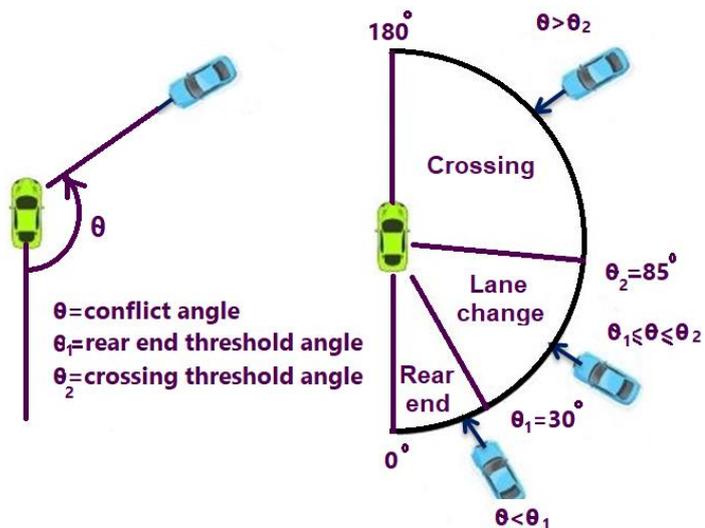
Figure (2-10) Conflict Angle Diagram [42]

Another description of the angle of conflict similar to the hand's watch is called the clock angle. Again, the angles of conflict are expressed from the first vehicle's perspective, clock time refers to the conflict angle in which the second vehicle is approaching from the first vehicle. for example, Position 12:00 refers to a direct ahead conflict of the first vehicle, Position 6:00 refers to a direct behind (rear-end conflicts), and 3:00 & 9:00 are indicating crossing conflicts, as illustrated in Figure (2-11).
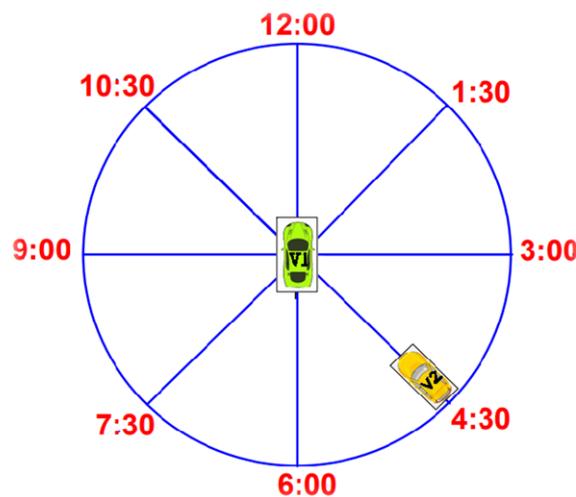
Figure (2-11) Clock Angle for Conflict Occurrence [42]**.**

2.11 Operation and Safety Performance

In traffic networks, signalized intersections are provided to increase the efficiency and safety of vehicle movements. However, the trade-off between these two elements is always a major problem. The majority of the current techniques assess the operation of intersections from the point of view of safety or efficiency separately. Also, there is a challenge in combining the operational and safety measures in a way to achieve both of them. Therefore, it is difficult to describe this relationship in general terms. Some countermeasures of intersections that would improve operational performance might also improve safety, but others might decrease traffic safety performance (FHWA) [73].

The LOS definition in the Highway Capacity Manual (HCM) 1965, 1985, 1992 included "safety". Beginning with HCM 1994, "safety" was removed from the LOS definition. LOS is a measure recommended to evaluate the operational performance of traffic facilities in terms, arrival time, capacity, and delay. It is symbolized from A to F letter, where the letter A representing the best-operating conditions while F is the worst (HCM 2010)[74]. For identifying LOS, there is a general agreement that LOS must be related too with traffic safety, Also Highway Safety Manual HSM refers to the importance of incorporating LOS in traffic safety research and establishing a LOS based on safety criteria. Unfortunately, this has not happened yet.

Many studies investigated the relationship between delay and road safety. A study conducted by (Workineh) presents an example of investigating the relationship between operating performance measure (OPM) and safety performance measure (SPM) using traffic conflicts as a surrogate measure of safety at the four-legged signalized intersection[75].

(Ying NI et al.) proposed a new method for evaluating signaled intersections from the safety and level of service perspective based on "multimodal level of service" MLOS (delay-related) and the "multimodal safety level " MSL (conflict-related) by using the simulation technique VISSIM model coupled with the SSAM model [76]. This study combined performance efficiency and safety level to evaluate intersections, The researchers provided a model for linking performance evaluation and safety evaluation at intersections, noting some parameters of the model need to be calibrated according to local conditions.

Table (2-5) summarizes a sample of the studies related to investigating the relation or/and incorporating between operation measures and the level of service.

Table (2-5) A Summary of Studies Relating Level of Service with Safety Performance Measure

Authors	Traffic facility	Finding
Jake Kononov and Bryan Allery,2003 [77]	Two-lane rural Roads and urban freeways	Four LOSs are suggested: LOS-I represents better safety performance, LOS-II represents a low potential for crash, LOS-III indicates less than expected safety performance, and LOS-IV represents a high potential for crash. LOS is described from the severity and frequency point of view.
A.Almonte 2009, [78]	multilane high speed arterial US	LOS C is related to a lowly severe crash frequency, while LOS E (unstable flow) is related to a highly severe crash frequency; Summarizing, the potential for a severe crash to happen at multilane high-speed arterial corridor increases as it approaches unfavorable traffic flow and/or operation situations.
Chengcheng Xu, et al.,2014 [79]	22-mile freeway segment US	The results indicated that the nature of the crash is completely different across different LOS, where LOS E was the most potential to crash, followed by Los F and LOS D, while LOS A and LOS B were the least potential to crash, For, LOS C crash risk was correlated with speed variation.
T. Campisi, et al.,2018 [80]	urban turbo-roundabout Italy	Through SSAM tool. Six scenarios are performed to evaluate flow characteristics by a combination of a ratio of bus rapid lines (BRl). The outputs of the different scenarios show this implementation provides benefits of safety in terms of LOS and values TTC and PET
J. Li, X. Wang, et al.,2018, [81]	Signalized intersections US	Rear-end and total crash occurrence decreasing on approach LOS A . Rear-end and total crash occurrence increasing on approach LOS C as the day progressed.
Wei Wang, et al.,2020 [82]	shared-use paths of road sections China	Model between service level and the number of conflict events of a shared path was established. Traffic comfort of the shared-use path was quantitatively described, and this made L.O.S' assessment of path sections more accurate

CHAPTER THREE

CHAPTER THREE

DATA COLLECTION AND METHODOLOGY

3.1 Introduction

High expenditures from traffic crashes at intersections due to poor layout, driving behavior, lack of lane markings, and constantly occurring dangerous maneuvers, provide a strong basis for safety improvement need.. To address this problem, a surrogate measure that is more effective and reliable should be sought for safety assessment, and this first requires quality and accuracy in data collection.

Data scanning is an essential work for modeling micro-simulations and other analyzes (field observed). Accurate survey data ensure the simulation accuracy for VISSIM software, thus reflecting the reality of the locations studied and providing reliable outputs for the safety assessment by SSAM (simulation approach).

3.2 Study Area

Intersections have always been a source of great concern to their users since are weak sites from the perspective of traffic safety, Therefore, The study area was chosen at three signalized intersections (two with four legs and the third with three legs), within Hilla city. It's the center of Babil Province, Intersections are located inside the urban CBD area. These intersections suffer high traffic volumes. Therefore, it has potential conflicts between vehicles. Moreover, during the data collection phase, uncivilized and unethical behavior of some drivers was observed, which is representing a lot of maneuvers and illegal crossing in order to shorten the travel time. Figure (3-1) illustrates the locations of these intersections.
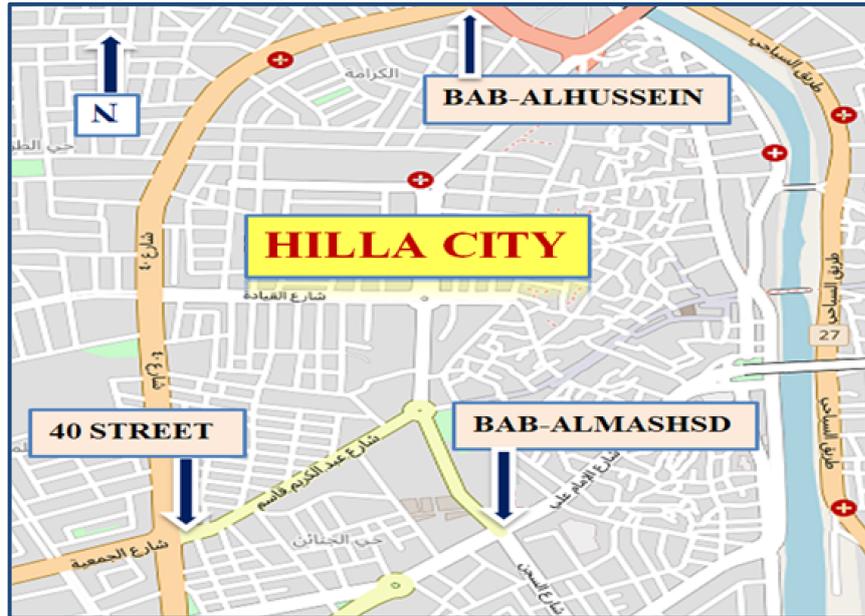
Figure (3-1) Base Map of Selected Intersections

3.3 Characteristics of Selected Intersections

Many characteristics affect the safety that must be described to simulate it by VISSIM version 10 simulation software to obtain a description that is as similar to the real-world situation as possible. In general, some characteristics of studied intersections are as follows:

- All legs of intersections have two-way streets.
- ALL approaches of intersections the same level (zero grade).
- No unusually heavy truck or bus traffic.
- All intersections operate at a fixed signal time for all phases throughout the day.
- No areas are specified for pedestrian crossing, Although there is pedestrian movement at these intersections.
- No existing parking and bus stop at/near-approaches.

According to these characteristics and the rest of the traffic and geometric characteristics, the intersections were modeled in VISSIM software. Table (3-1) displays the locations and shapes of intersections.

Table(3-1) Types and Locations of Studied Intersections

Intersections name	Type	Location	
		Latitude	Longitude
40 Street	4-leg	32°28'25.1"N	44°25'31.0"E
Bab Al-Mashhad	4-leg	32°28'26.1"N	44°25'58.7"E
Bab Al-Hussein	3-leg	32°29'22.8"N	44°25'56.2"E

3.4 Data Source

The data are the basis of this study as mentioned earlier, in order to obtain accurate results, the data used should be as detailed as possible about the study sites because they are considered essential inputs in creating the trajectory file by the VISSIM model, Also, It is responsible for calibrating the simulation model and validating the results of SSAM, the data collected consists of five stages as follows:

Stage one: - Traffic data

Stage two: - Geometric characteristics data.

Stage three: - Traffic conflict data.

Stage four:- Data of calibration

Stage five:- Data of crashes

The essential input source to the VISSIM simulation and the SSAM analyses software are the values of the first and second stages of data collection. Simultaneously, the same values are used in the field approach combined with the third stage data, which is the basis of the field study (field conflict) in this thesis, the fourth stage data were used to calibrate the VISSIM model.

While the fifth stage data (crash data) were collected despite its inaccuracy in most of the data. Or rather, crash records do not contain detailed data that can serve as a reference for safety assessment. But it was collected as information to enrich the reader only. Figure (3-2) shows the method of data collection and methodology of the study.

Data Collection

Calibration Data | Traffic Data | Geometric Data | Conflict Data | Crash Data

Speed Data | Volume Data

Lane width, No .of lane Radius length…etc.

No. of crash , location & type crash

Average standstill distance, Front Gaps etc

No.of conflicts and types

Police offices and some related authorities

Phase 1

Phase 2

For information only

By VISSIM micro-simulation software

Using other parameters

Running the Simulation and Exporting Trajectory files to SSAM

By field observing of conflicts

Conflict analysis results by (SSAM) Model

Outputs of traffic conflicts

Outputs of traffic conflicts used to validation SSAM

Compare

No

Good correlation

Yes

Conclusion and Recommendations

Figure (3-2) Data Collection and Methodology of Study

3.4.1 Traffic Data

To carry an analysis of safety by simulating the traffic condition, as well as manual safety analysis that is required to validate SSAM Software, one of the basic data sets required is the traffic volume data. These data are collected from the site by the videotaping method. The data include the number of vehicles turning to the left, right, U-turn, and moving on each intersection approach. Four cameras were used on each side to cover the entire intersection, each camera recorded videos for 8 hours. Tables (3-2) offer the traffic volumes at approach AL-Zraaha for 40 St. Intersection.

Table(3-2) Traffic Volume Data at AL-Zraaha Approach for 40 St. Intersection

Time	Approach	Traffic Volume (veh./15 min)					
		Days of Observation					
		Sunday / 8-11-2020			Monday / 9-11-2020		
		Left	Through	Right	Left	Through	Right
7:30-7:45		90	183	43	88	179	40
7:45-8:00		62	142	48	60	149	44
8:00-8:15		71	99	45	69	89	42
8:15-8:30		63	180	42	62	181	47
Total		**286**	**604**	**178**	**279**	**598**	**173**
8:30-8:45		79	152	39	80	140	40
8:45-9:00		85	92	45	82	84	40
9:00-9:15	AL–Zraaha	65	152	42	60	144	44
9:15-9:30		72	105	39	60	98	36
Total		**301**	**501**	**165**	**282**	**466**	**160**
12:30-12:45		84	202	40	85	179	37
12:45-1:00		56	198	45	51	181	43
1:00-1:15		67	95	43	70	82	43
1:15-1:30		53	248	39	50	227	32
Total		**260**	**743**	**167**	**256**	**669**	**155**
1:30-1:45		72	141	35	72	140	33
1:45-2:00		83	85	40	87	79	41
2:00-2:15		54	202	41	44	187	42
2:15-2:30		66	298	34	67	277	35
Total		**275**	**726**	**150**	**270**	**683**	**151**

The cameras were set up in each approach of the intersection to record the traffic volume. Data collection was conducted during peak hours. The data

were collected from 7:30 a.m. to 9:30 a.m., and 12:30 p.m. to 2:30 p.m. on two consecutive days. The recorded videos were reviewed for obtaining traffic volume. The data collection period continued through November and December 2020. Table(3-2) shows the dates of the video recordings, peak hours, and peak hour volume.

Table (3-3) Videos Recording Date, Peak Hour, and Peak Hour Volume for the Studied Intersections

Intersection	Date	Start Time	End Time	Peak Hour	Peak Hourly Volume
40 St.	Nov.7th,2020[*]	7:30 12:30	9:30 14:30	7:30-8:30 a.m	4126
	Nov.8th,2020	7:30 12:30	9:30 14:30	7:30-8:30 a.m	
Bab ALMashhad	Nov.22th,2020[*]	8:30 12:30	10:30 14:30	8:30-9:30 a.m	3179
	Nov.23th,2020	8:30 12:30	10:30 14:30	8:30-9:30 a.m	
Bab ALHussein	Dec.6th,2020[*]	8:00 12:00	10:00 14:00	8:00-9:00 a.m	4747
	Dec.7th,2020	8:00 12:00	10:00 14:00	8:00-9:00 a.m	

[*]Peak day

To model the traffic volumes inside by VISSIM model, the composition of the vehicles must be determined. Tables (3-4) display the vehicles compositions at approach ALZraaha-40 Street of 40 St. Intersection. Appendix B presents the traffic volume data vehicle Compositions for the rest three legs of the 40 St. Intersection.

Table(3-4) Vehicles Compositions/Types at Peak Hour at 40 St. Intersection

*Vehicle Compositions	Number of Vehicles				Proportion
	Left	Through	Right	U-Turn	
Car	264	569	160	0	92.98%
HGV**	9	19	14	0	3.93%
Bus	13	16	4	0	3.09%

*According to VISSIM, the basic vehicle Compositions include (Car, HGV, Bus, Tram, Bike, and other types that can be added to the Software)[52].
** A European term use in VISSIM Software for Heavy Goods Vehicles (HGV)[6], which is divided into three classes according to their total mass (N1, N2, N3).

Figures (3-3) to (3-5) show the traffic volumes at peak hour .While plates (3-1) to (3-3) present screenshots from video recorded for sites.
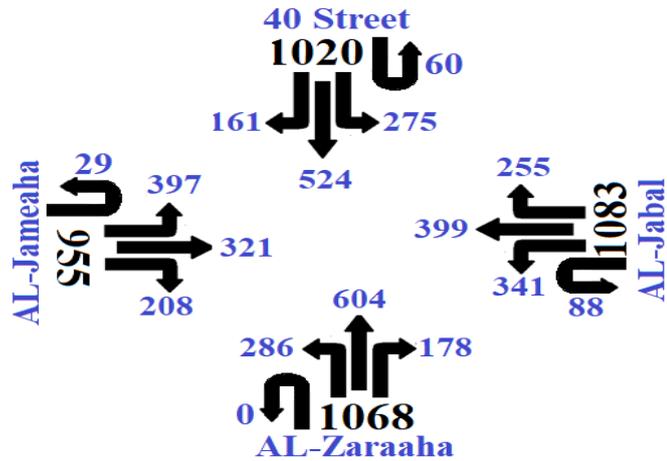
Figure (3-3) Peak Hour Volume (8:30-9:30 a.m) at 40 St. Intersection
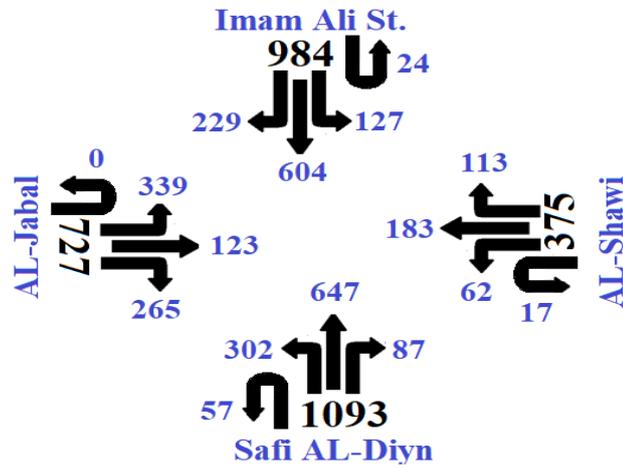
Figure (3-4) Peak Hour Volume (8:30-9:30 a.m) at Bab Al-Mashhad Intersection
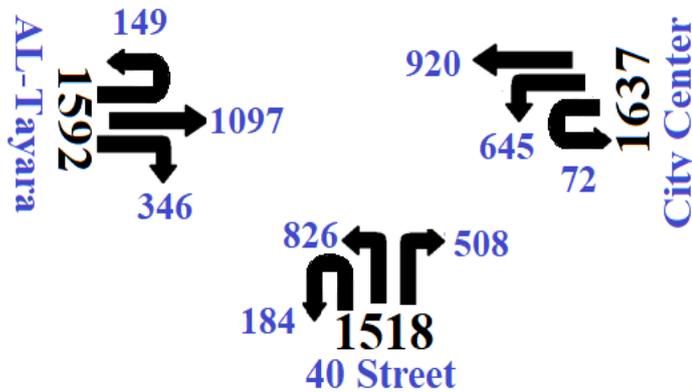
Figure (3-5) Peak Hour Volume (8:00-9:00 a.m) at Bab Al-Hussein Intersection

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Plate (3-1) Video Screenshot of Traffic Movements at 40 St. Intersection

Plate (3-2) Video Screenshot of Traffic Movements at Bab-AL Hussein Intersection

Plate (3-3) Video Screenshot of Traffic Movements at Bab-AL Mashhad Intersection

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3.4.1.2 Speed Data

Speed is important in all modes of transportation consideration because it relates primarily to safety and travel time, comfort, etc. The spot speeds survey was conducted at each approach to define the values and input them in the VISSIM model. A spot speed is a study of the speed of traffic at one point, it consists of a series or a sample of observed individual vehicles' speeds.

There are two basic methods employed to measure speed: one involves the measurement of time and distance, and the other takes advantage of the Doppler principle. The time versus measured distance method is the most commonly used; it involves the measurement of the time required for a vehicle to traverse a measured course.

The Institute of Traffic Engineers has recommended certain base lengths for spot speed determination at different average speed ranges of the traffic stream as shown in Table (3-5) below.

Table (3-5) Recommended course length [83]

No.	Average speed of traffic stream(mph)	Course length (ft)
1	Less than 25	88
2	25 to 40	176
3	Greater than 40	264

The measured length is identified beyond the queue approach [84]. The length of the course is dependent upon the average speed and the type of location. The shorter measured course 27 m is normally employed for the intersection approach and the longer ones (176 or 264 feet) for other locations where speed is relatively more constant, for implementation, the simplest and most direct method was used speed determination use transverse pavement markings (painted signs) which were placed at the start and end of the measured course when the vehicle reaches the first

mark, the observer begins recording the start and end time of each vehicle that has crossed the predetermined distance, as shown in figure (3-6).
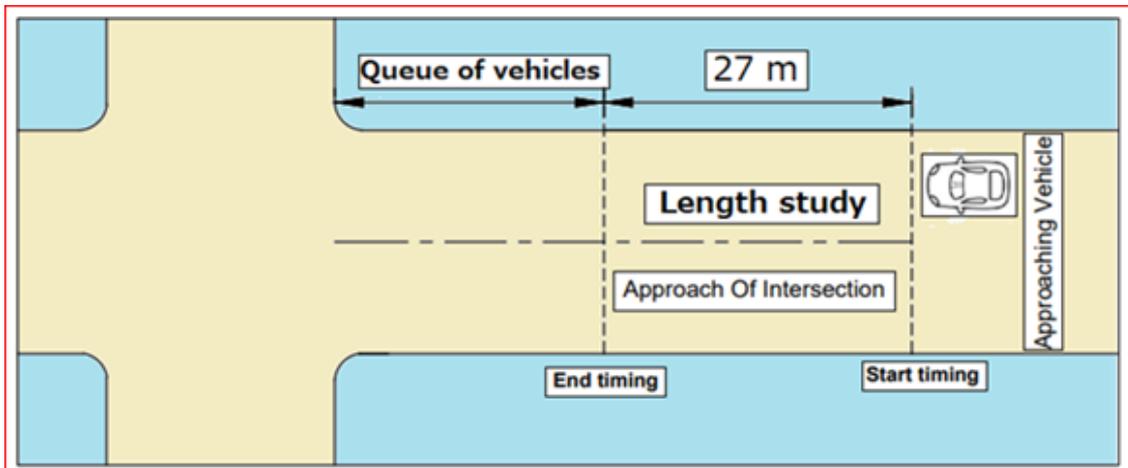
Figure (3-6) Speed Measuring Principle Based on Distance and Time

To calculate the minimum sample size for the normal distribution of spot speed data, the following equation can be used.

$$N = \left(\frac{Z\sigma}{E}\right)^2 \quad [84] \quad \textbf{(3.1)}$$

Where

$N=$ Lowest sample size.

$Z=$ Number of standard deviations that correspond to the confidence of the level required.

$\sigma=$ Standard deviation (km/h)

$E =$ Acceptable limit of error in the average speed estimation (km/h).

The permissible error may range from ± 6 km / h to ± 1.5 km / h or less depending on the purpose of the study. However ± 2 km / he was used to correct the error in the measurement [84]. Table (B-6) shows a sample of spot speed data for the 40 St. Intersection.

3.4.2 Geometric Characteristics Data

Of the many reasons for the causes of traffic crashes are geometric characteristics of roads, they play an important role in preventing or reducing crashes. There is very little research in developing countries into the relationship between geometric characteristics of intersections and crash rates. The most geometric characteristics data were measured at the intersections such as the number of lanes, lane widths, and turning radius.

The data also covered important aspects, including median width and the existence of the island to move to the right or not. The geometry of the intersection and approaches should be studied accurately in order to make the VISSIM simulation software similar to the field conditions. Details of geometric characteristics for each intersection are demonstrated in Table (3-6). While geometric layouts were represented in Figures (3-7) to (3-9).

Table (3-6) Geometric Characteristics and General Description of Intersections in the Study Sites

Intersection Name	Approach Direction	From	To	No.of Lanes	Lanes Width (m)	Median Width (m)	Exclusive RT***
40 Street	NB	AL-Zraaha**	40 Street	3	3.4	4.2	Yes
	EB	AL-Jameaha	AL-Jabel	3	3.3	2.5	Yes
	SB	40 Street**	AL-Zraah	3	3.4	3.5	Yes
	WB	AL-Jabal	AL-Jameaha	3	3.2	1.2	Yes
Bab-AL Mashhad	NB	Safi ELDiyn**	Imam Ali St.	3	3.5	2.1	No
	EB	AL-Jabal	AL-Shawi	2	3.6	-	No
	SB	Imam Ali St.**	Safi EL-Din	3	3.5	2.5	No
	WB	AL-Shawi	AL-Jabel	2*	3.6	0.7	No
Bab-AL Hussein	NB	40 Street	-AL-Tayraa - City Center	3	3.1	2.3	Yes
	EB	AL-Tayraa**	City Center	3	3.0	4.4	Yes
	WB	City Center**	AL-Tayraa	3	3.5	1.3	No

*: One out of two lanes are closed for security reasons   **: major street
*** Existing channelizing island for right movement.
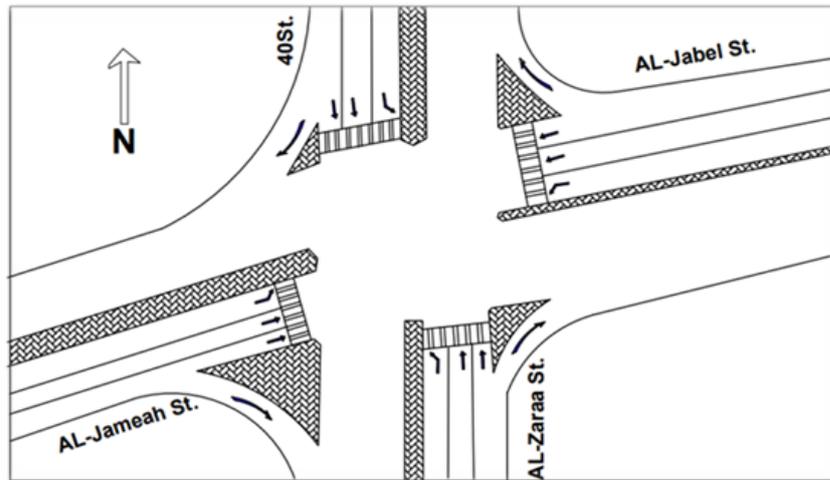
Figure (3-7) Geometric Layout of 40 St. Intersection
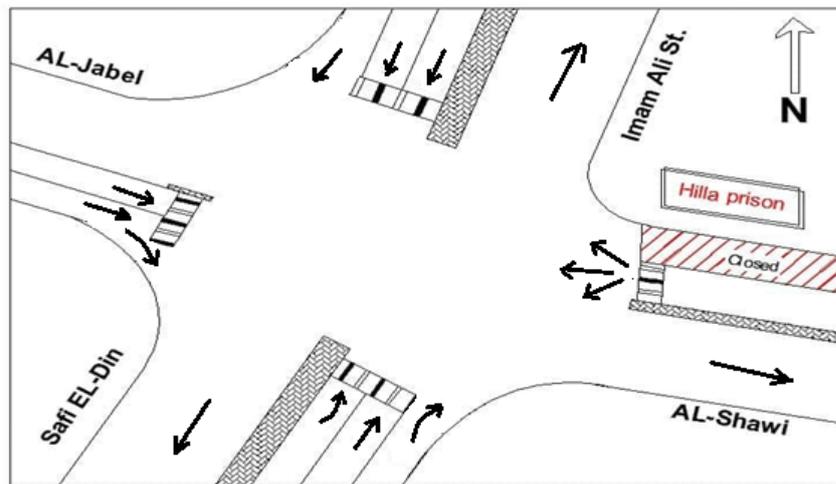
Figure (3-8) Geometric Layout of Bab-AL-Mashhad Intersection
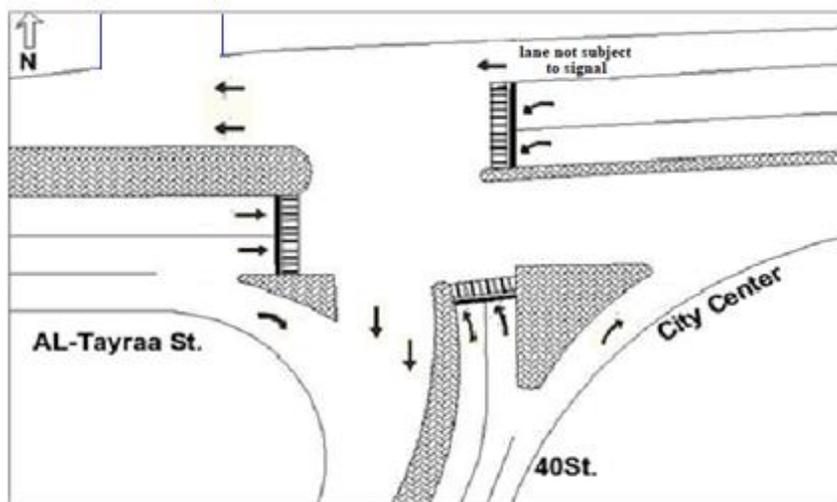
Figure (3-9) Geometric Layout of Bab-AL-Hussein Intersection

3.4.3 Traffic Conflict Data

Traffic conflicts data in the field were extracted from cameras that recorded traffic volumes, According to previous studies, the conflict monitoring zone should cover the functional zone of the signalized intersection (Parker and Zegeer) [72]. The cameras were set up on the top of roadside buildings to achieve an adequate view of intersections.

Types of conflicts were recorded by observing evasive actions taken by road users to avoid collisions such as deceleration, swerving, and braking. The sudden deviation of vehicles or a change lane from one lane to another was another indicator of the observed conflicts and it was included in the lane change conflicts. Also, deceleration vehicle speed or application to vehicle brakes is included in the type of rear-end conflicts. The conflicts were classified according to the definitions provided by (Parker and Zegeer) [72], which were divided into six types, as shown in Figure (3-10).

(a) Left-turn, same-direction conflict

(b) Slow-vehicle, same-direction conflict

(c) Right-turn, same-direction conflict

(d) Lane-change conflict

(e) Right-turn, cross-traffic-from-right conflict

(f) Opposing left-turn conflict
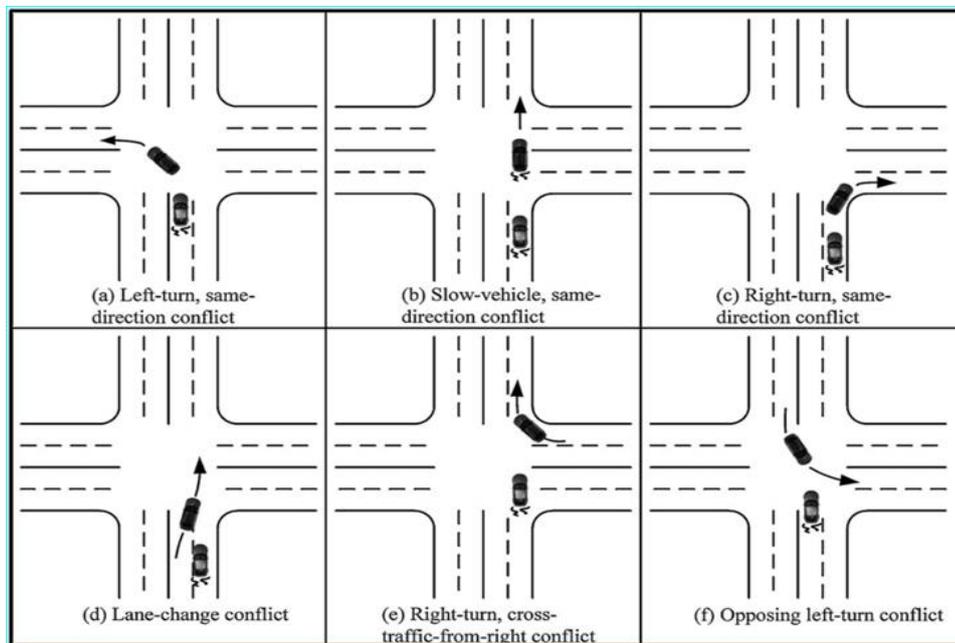
Figure (3-10) Conflict Types Observed in the Field

In order to compatibility, between the field conflicts with the results of the SSAM conflicts by simulation, the conflicts of the observation in the field were combined on the basis of the angles of the conflict used in the SSAM pattern. In particular, types 1 to 3 were classified as Rear-end conflicts, and the 4 & 5 types were classified as lane-change conflicts while type 6 was classified as a cross conflict. Table (3-7) shows the conflicting data at the 40 St Intersection that was collected from the field to mainly be used to validate the validity of SSAM.

Table (3-7) Conflict Data at 40 St. Intersection

Time	App.	Traffic Conflict /h								Total TC/h
		Rear-end Conflict				Lane-change Conflict			Crossing Conflict	
		C1	C2	C3	Total	C4	C5	Total	C6	
*7:30 - 8:30	NB	4	4	2	10	3	3	6	2	66
	EB	3	2	1	6	3	2	5	1	
	SB	2	4	3	9	4	1	5	2	
	WB	4	7	2	13	3	2	5	2	
*8:30 - 9:30	NB	4	3	2	9	2	2	4	2	53
	EB	2	1	1	4	2	-	2	2	
	SB	2	3	2	7	3	1	4	2	
	WB	2	6	4	12	3	2	5	-	
*12:30 - 1:30	NB	3	5	3	11	3	1	4	1	55
	EB	4	2	2	6	2	1	3	1	
	SB	3	2	3	8	2	2	4	2	
	WB	2	6	3	11	3	1	4	-	
*1:30 - 2:30	NB	5	3	2	10	2	4	6	3	57
	EB	3	3	-	6	3	1	4	-	
	SB	3	4	2	9	2	3	5	1	
	WB	4	2	1	7	2	2	4	2	

*Represents conflicts data for interval four peak hours for one observation day out of two days.

3.4.4 Calibration Data

Once the conflict data have been identified to conduct validation of the simulation approach, a new group of data must be collected. which is calibration data. calibration data were collected from the field over two days. It is necessary to calibrate driving behavior parameters and to specify an acceptable range of parameters. In order to represent the reality of the driver's behavior in the study sites.

Many parameters in VISSIM software can be calibrated. Researchers suggested the following parameters for calibration: clearance distance, Driving behavior on adjacent lanes distance, lane change distance, minimum headway, and standstill distance.

Some calibration data shown in Table (3-8) were collected for ease of obtaining them through the questionnaire or measurement in the field, Others were left because of the difficulty of measuring them in the field.

Table (3-8) Some Driving Behavior Parameters Data for VISSIM

Intersection	Approach	Driving Behavior Parameters*			
		Average standstill distance (m)	Lock ahead distance (m)	Vehicles occupation of the wrong lane Volume %	Driving behavior on adjacent lanes distance (m)
40 St.	NB	1.50	100	11	1.10
	EB	1.60	80	7	1.10
	SB	1.60	90	13	1.00
	WB	1.70	85	8	1.10
Bab-AL Mashhad	NB	1.70	85	14	1.00
	EB	1.60	80	10	1.00
	SB	1.60	80	11	1.20
	WB	1.70	65	0	0.00
Bab-AL Hussein	NB	1.60	100	9	0.80
	EB	1.50	110	5	1.10
	WB	1.50	85	0	1.00

* The description is illustrated in Chapter Four VISSIM Calibration Analysis.

3.4.5 Crash Data

Crash databases of the study sites should be available for multiple years so as to carry out a statistical diagnosis safety sound[56]. Unfortunately, the crash data, which are published by the Central Statistical Organization (CSO) of the Iraqi Ministry of Planning, publishing reports on the crash at the governorate and district levels and does not specify the location and type of traffic facility in which those crashes occur.

As a result, the source of fault data is the Traffic Department through crash reports prepared by the traffic police officers responsible for recording crashes. Plate (3-4) shows traffic crashes at 40 St. Intersection obtained during the crash data collection stage.

Plate (3-4) Screenshots for Crashes Data Collected at 40 St. Intersection

Table (3-9) displays the number of crash data for study sites. Despite this, the crash data lack accuracy because not all crashes are reported (e.g., conflicting persons are reconciled) and crashes often it is located outside the area of the intersection but recorded in the intersection or contrary. The definition of an intersection crash tends to vary between agencies. Some agencies have taken into account all crashes within a specified distance, such as 250 ft, from the center of an intersection to be intersection crashes (AASHTO, 2010) [1].

Table(3-9) Vehicle Crash Data for the Studied Locations

Intersection	2017	2018	2019
40 Street	4	5	4
Bab-AL Mashhad	2	3	3
Bab-AL Hussein	4	3	3

3.5 Software Used in This Study

In addition to Statistical Package for the Social Sciences (SPSS) and Geographic Information System (GIS) software, the two main software were used in this study, namely the VISSIM micro-simulation model and SSAM. Below is a brief description of each.

3.5.1 VISSIM Software

VISSIM is one of the software packages launched and developed by PTV Group **P**lanung **T**ransport **V**erkehr at the University of Karlsruhe in Germany, which means in English language planning transport traffic. It was initially designed to simulate traffic in cities, hence the name VISSIM comes in German (**V**erkehr **I**n **S**tädten **SIM**ulationsmodel)[85], but the mode for freeway simulation is also added later.

Recent software updates have allowed simulated pedestrian flows besides public transportation such as transportation by rails and planes. In this study, PTV VISSIM 2020 - version 10 Student license was used. Figure (3-11) presents a screenshot of the framework of VISSIM software.

Figure (3-11) Screenshot for the Framework of VISSIM Software

3.5.2 SSAM Software

SSAM is a popular and familiar use software at many professionals and those interested in traffic safety, developed by the US Department of Transportation - Federal Highway Administration (FHWA) in 2003 with funding from Siemens to evaluate traffic safety by calculating safety measures through reading trajectory files that generated from simulation models.

The name of the "SSAM" software is elicited from the acronym of the Surrogate Safety Assessment Model[63]. SSAM-VISSIM coupling resulted in a new approach to safety assessment in traffic facilities called the simulation approach. Figure (3-12) illustrates a screenshot of the framework of SSAM software.
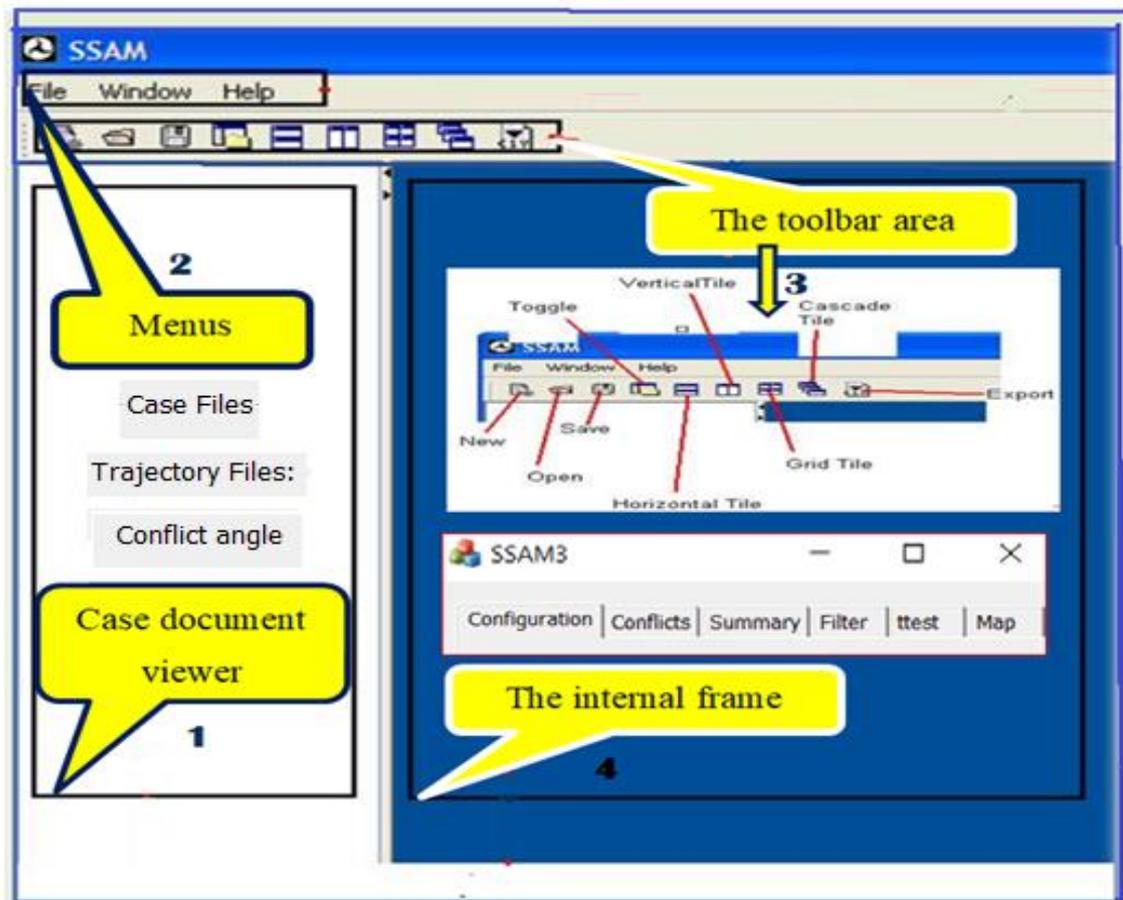
Figure (3-12) Screenshot for the Framework of SSAM Software

3-6 VISSIM Methodology in Creating a Trajectory File

To conduct a traffic safety analysis in the SSAM model properly, it is necessary to create an accurate Trj file to obtain accurate results. Therefore, VISSIM considered is the basis because it is responsible for simulating the movement of vehicles, recording interactions, and everything related to safety.

A quick presentation of the most important steps for modeling and creating the Trj file for intersections (except for speed modeling was conducted fully analyzed in the Data Analysis chapter).

Step 1: Intersections Specify on the Network

Determine sites on the network were through the user interface of the VISSIM software that connected with the Street Map contributions, this link between VISSIM and Street Maps from Google Map is very important to increase the accuracy in determining the geometric properties of the site beside captured data from the field. Figure (3-13) presents a screenshot for the network of VISSIM software.
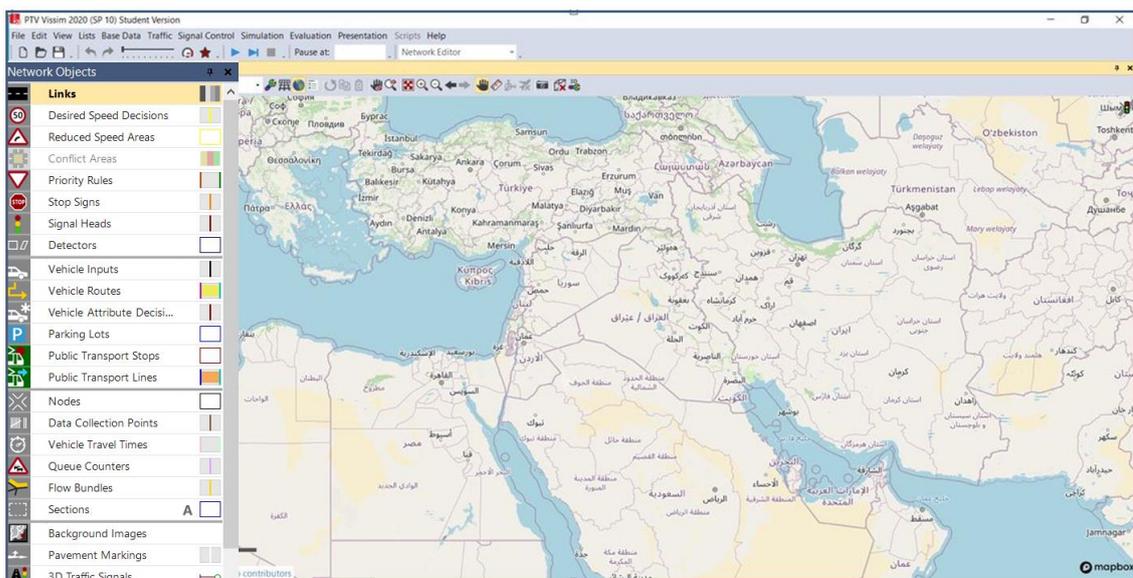
Figure (3-13) A Screenshot of the Street Map Network of VISSIM

Note: All information and modeling procedure steps for intersections are taken from the VISSIM 2020 user manual.

Step 2: Setting up Links and Connectors

Link is the main component of the road network in VISSIM software. Links generally refer to roads in networks, and connectors refer to the connection between those roads, links at intersections represent approaches of intersections. Traffic flows are done through links only in one or more lanes. Figure(3-14) shows the links, the number of lanes, and the width of each lane. It also shows the connectors that connect these links
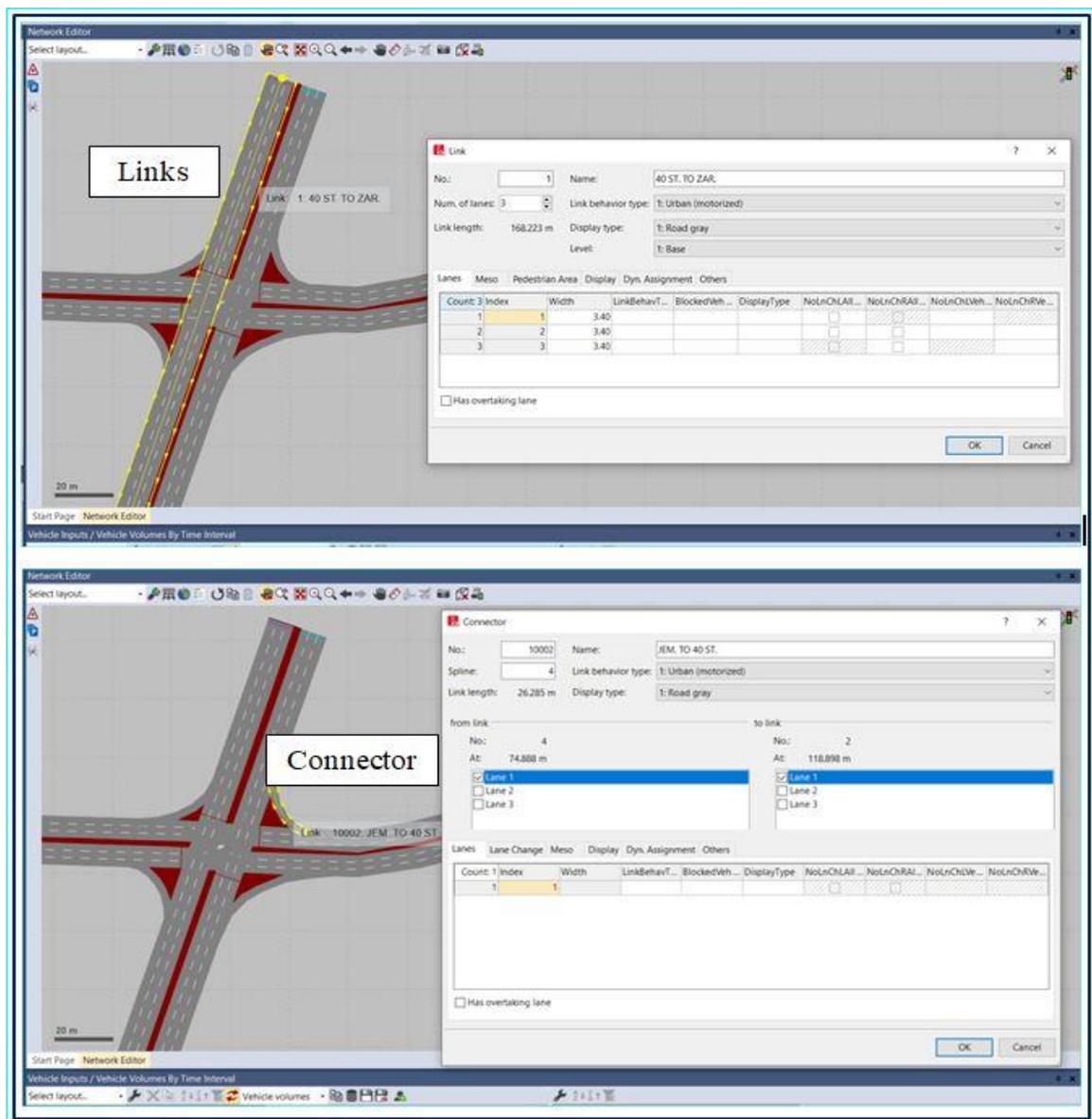
Figure(3-14) A Step of Establishing Links and Connectors and Their Characteristics at 40 St. Intersection

Step 3: Assigning Inputs/Volumes and Compositions of Vehicles

Traffic flow occurs from the vehicle's input; entering vehicle volume/input is only positioned on links/networks. VISSIM deals with traffic volumes that drawn from the field in the vph unit. Vehicle compositions include multiple types of vehicles (car, bus, tram, HGV, etc.) so that the sum of all these types is 100% of the traffic flow. Figure (3-15) illustrates vehicle compositions as well as shows vehicle inputs.
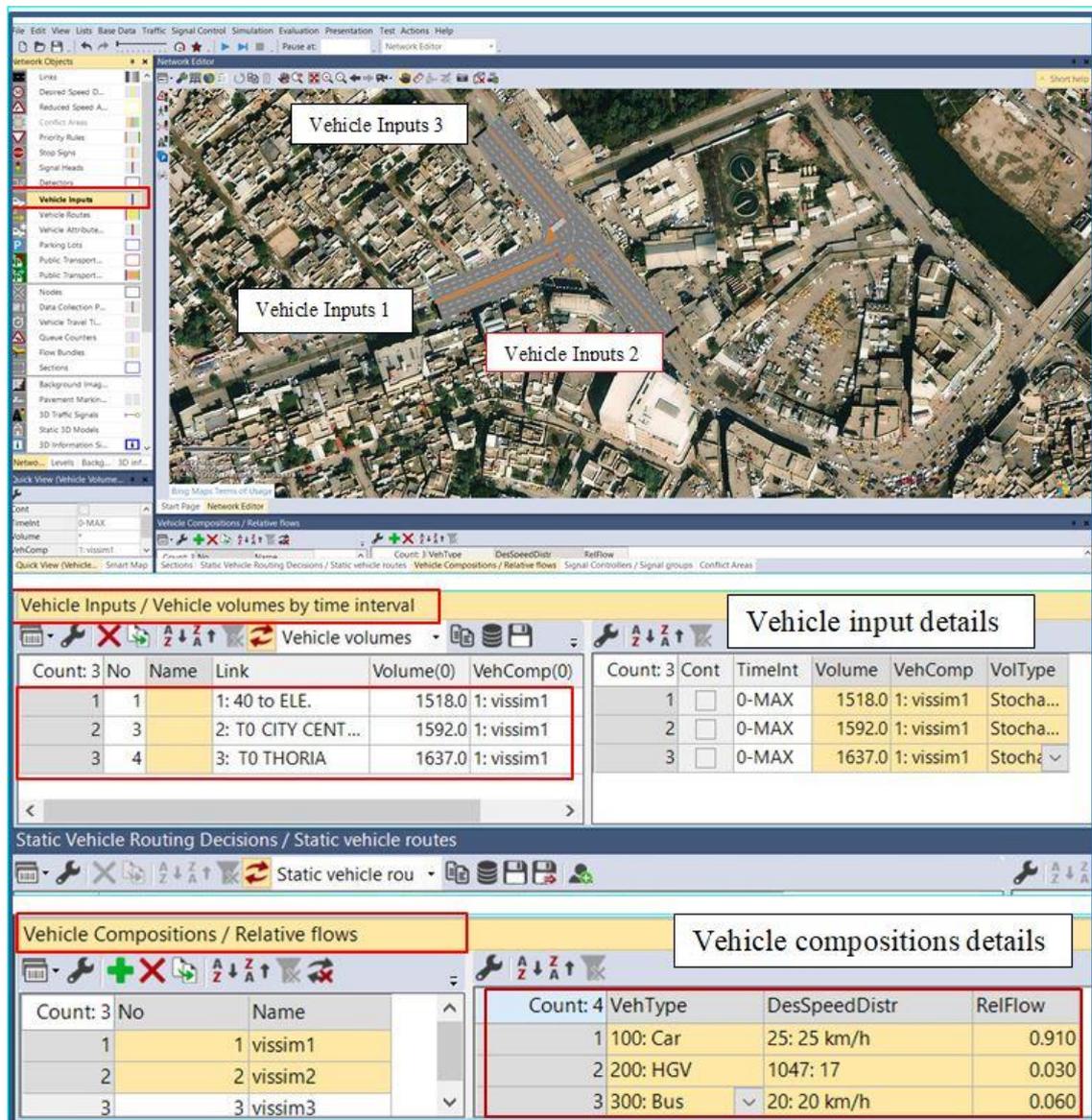
Figure(3-15) Assigning Inputs and Compositions of Vehicles at Bab-AL-Hussein Intersection

Step 4: Route of Vehicles

Vehicles that start from one link rarely remain on the same link, each vehicle has its own destination. Therefore, all routes of vehicles departing from one link to multiple links must be determined. The ratio of each route volume from the total traffic volume must be determined so that the total volume percentage in all routes is 100%.

Figure (3-16) shows the branching of the vehicle routs departing from the northern approach of the 40 St. Intersection. If VISSIM detects no route between the starting section (purple color) and the end of destination sections (turquoise color), either a connector does not exist or the condition/position of the connector is wrong.
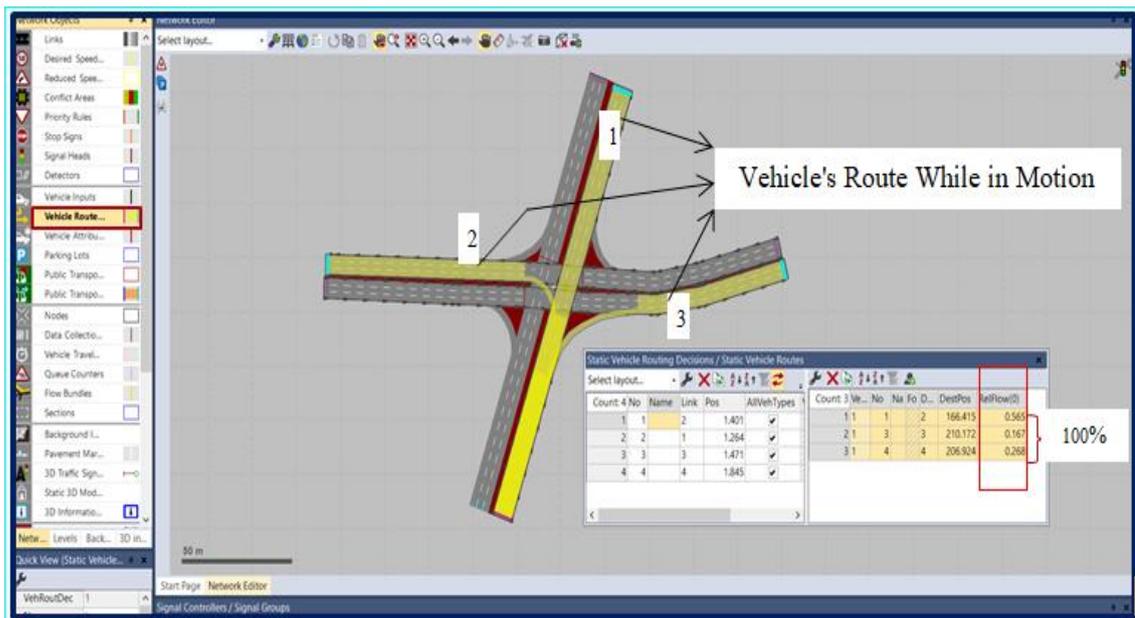
Figure(3-16) Process of Determining Route of the Vehicles at Northern Approach at 40 St.Intersection

Step 5: Modeling Signal Timing

VISSIM is able to simulate a traffic light and its effect on the behavior of the driver within 100 meters of the stop line. VISSIM simulates signal light through signal control (SC) which allows modeling the cycle time procedures. The traffic sign modeling process inside VISSIM is complex Figure (3-17) illustrates part of the stages of modeling the light signal. Following is a summary of some steps to modeling it.

- Creating a signal group with the same number of intersection legs.

- Determine the sequence and the state of the signal (there are 11 default states of signal sequence in the VISSIM model).

- Entering the cycle time for an intersection and set a green, yellow and red time for each approach.

- Determine the vehicle stop line and activating it to correspond to the signal headlight.
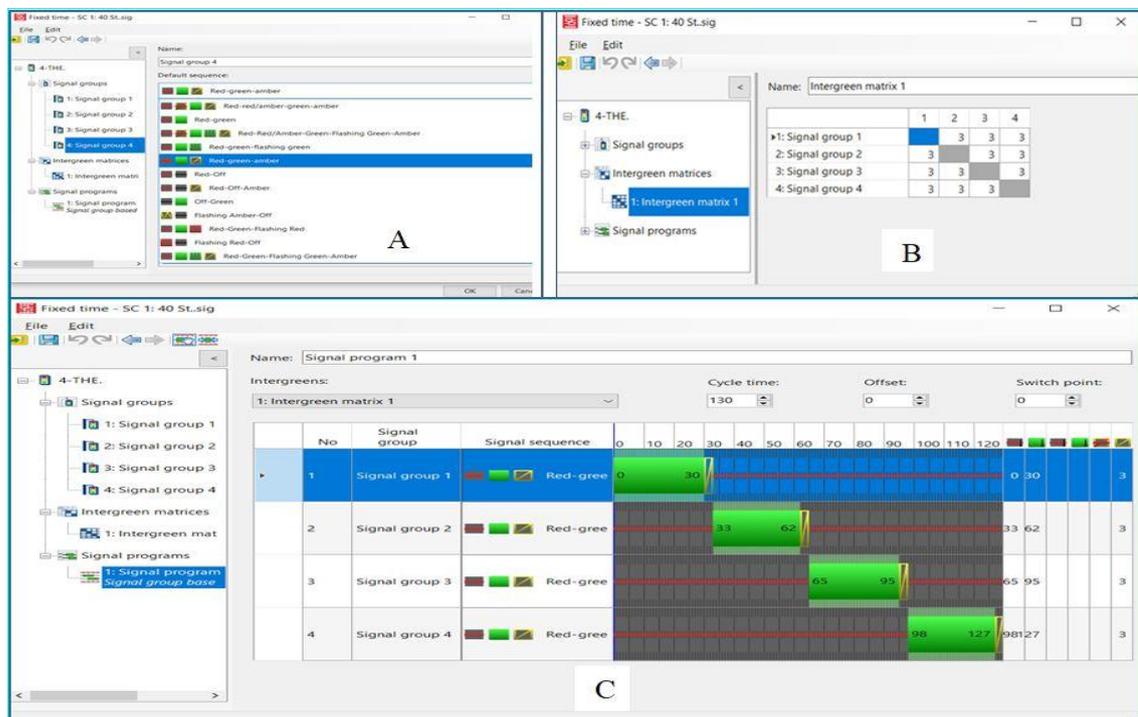
Figure (3-17) Multiple Screenshots Illustrating Stages Modeling Traffic Signal Timing

Step 6: Matching Trajectory File Format With SSAM Analysis

After modeling intersections through determining all geometric and traffic characteristics, The simulated vehicle trajectories files in the network (within one section or multi-section) are saved in the (Trj) format (Trj) files contain information and attribute about simulated vehicle trajectories such as (coordinates (x, y, z), time, speeds,...etc.). Then, (Trj) is uploaded to the (SSAM) that affiliates to the (FHWA).

Figure (3-18) illustrates the steps for saving the data format, starting from the direct output evaluation to specifying the SSAM option, The time period of trajectory file evaluation of SSAM analysis requirements (from 0 - to 3600 s), determining the scope of the data by entering a section of the VISSIM network where can select the desired section. And ending with simulation running (described in step 8) Trj content cannot be interpreted by a text editor or program except the SSAM model.
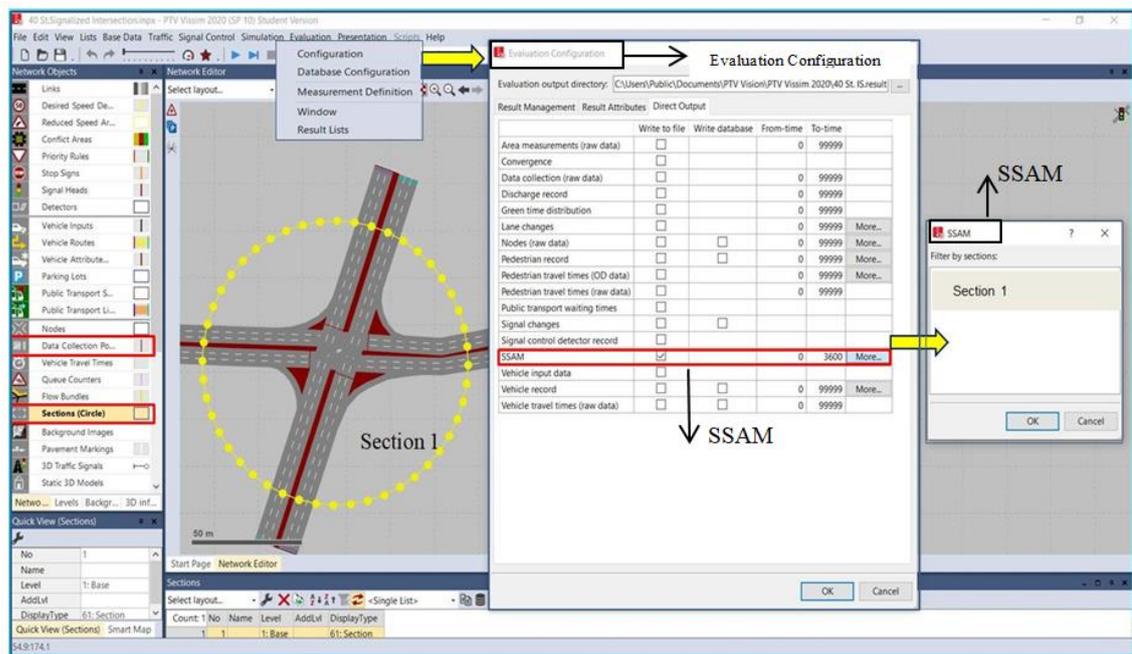
Figure (4-18) Configuration the Output of the Trj File and Exporting it to SSAM

Step 7: Simulation Running

To conduct a traffic safety assessment for the three sites using the SSAM model requires these running the simulation process to record and store all the characteristics of the vehicle movement during the simulation, such as (maneuvers, interaction, acceleration, deceleration, lane change, conflict areas, and others).

Running the simulation can be displayed in 2D / 3D model as shown in Figure (3-19) and this sometimes allows the traffic engineer to better understand the reality of the traffic network and contribute to initial decision-making. The simulation was run 10 times for each file with different scenarios in order to obtain sufficient statistical data as well as to represent the reality of the real world more closely.
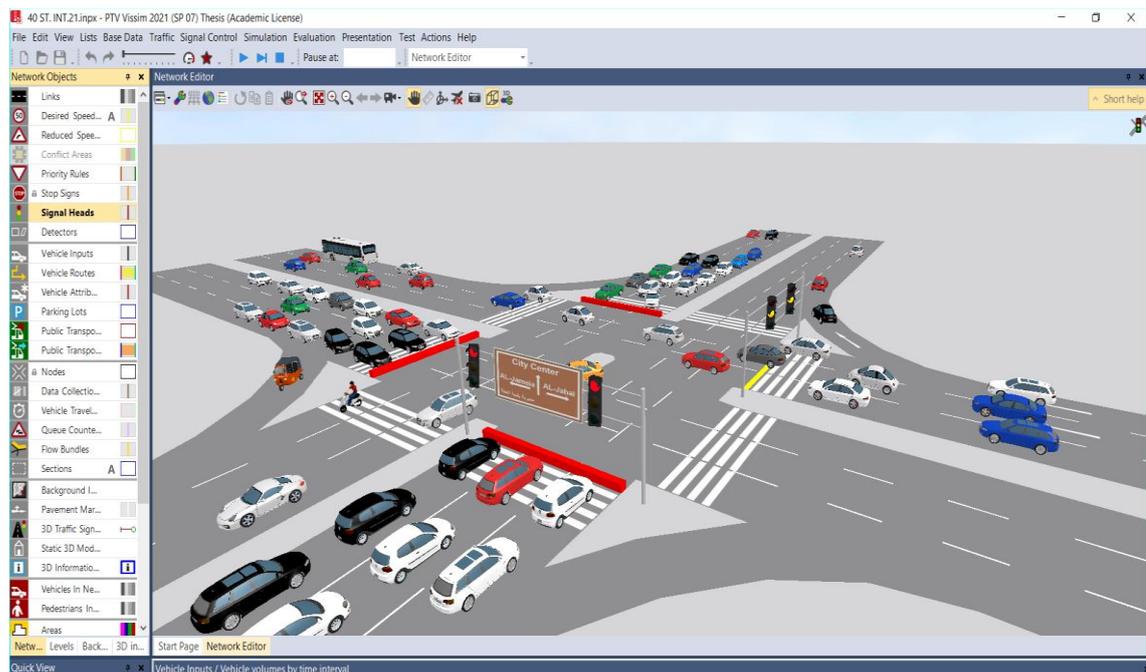
Figure (3-19) A 3D Mode Screenshot Showing the Simulation Run at 40 St. Intersection

Moreover, in Appendix (C), some figures show the reduced-speed areas, some attributes of some conflict areas, a closed lane for the Bab Al-Mashhad intersection, and lane no undergo to signal light at Bab-AL Hussein Intersection.

CHAPTER FOUR

CHAPTER FOUR
ANALYSIS AND DISCUSSION OF RESULTS

4.1 Introduction

Traffic safety measurement or estimation is considered itself, is complex due to the presence of many factors that affect it. And it is oftentimes hard to be described safety exactly by using a mathematical model or empirical technique, But by using simulation technology, it can take advantage of converting complex traffic movement into a visual image that is easy to understand and analyze.

4.2 Simulation Parameters

The vehicle's behavior and its interactions are influenced by the simulation resolution except for simulation speed. Setting the basic parameters of the VISSIM simulation model are following:-

- The simulation period is set to 3600 seconds and this time represents a peak hour time.

- The simulation start time has been set from zero. This allows SSAM to perform conflict analysis for an hour.

- The number of simulations was set to 10 runs with random seeds differing in each run. i.e. 10 seeds were used

- The Simulation resolution, which defines how repeatedly vehicle locations are re-calculated at one-second simulation, was identified in 10 places. The value should not be less than 5 and the best between 10 and 20.

- Simulation speed time per second compare to real-time, the simulation speed does not affect the simulation results, but it is a

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very important parameter to shorten the result time and accomplish the largest simulation runs within a reasonable time. In this study, this feature facilitated conducting more than 3000 hours of simulation, so the simulation speed is set to 10 (value 10 represents a simulation speed equal to (10) times the real-time while value (1) represents a simulation speed equal to real-time.

Referring to the steps for creating trajectory files for the movement and interactions of vehicles described in Chapter Three Article (3.6), it is now SSAM's turn to analyze the trj file data, but before that, the velocities must be modeled in VISSIM

4.3 Vehicles Speed Identification

Despite the intersection areas are characterized by low speeds and fairly close to each other, unlike other traffic facilities, speed remains a risk factor in these areas as speed increases the potential crashes. To calculate the spot speed, a test of normality for speed data has been conducted using SPSS statistical analysis software as shown in Table (4-1).

Table (4-1) Normal Distribution Test and the Descriptive Statistics of Speed.

Kolmogorov-Smirnov -Test of Normality		
		Speed
Normal Parameters[a,]	Mean	22.3427
	Std. Deviation	2.43911
Most Extreme Differences	Absolute	.130
	Positive	.130
	Negative	-.062-
Test Statistic		.130

a. Test distribution is Normal.

Descriptive Statistics						
	N	Mean	Range	Variance	Minimum	Maximum
Speed	99	22.3427	9.87	5.949	18.38	28.25

According to the test, the outputs of speed data collected have a normal distribution. In the VISSIM simulation model, the mean speeds of the observed sample to represent one hour were used. Ninety-nine vehicles were observed at each intersection approach.

To identify the spot speed for a sample of individual vehicles the spot speed data were sorted on the basis of samples and the speeds were distributed in categories and the number of vehicles observed for each category was recorded. Figure (4-1) presents a histogram distribution of the recorded speed.
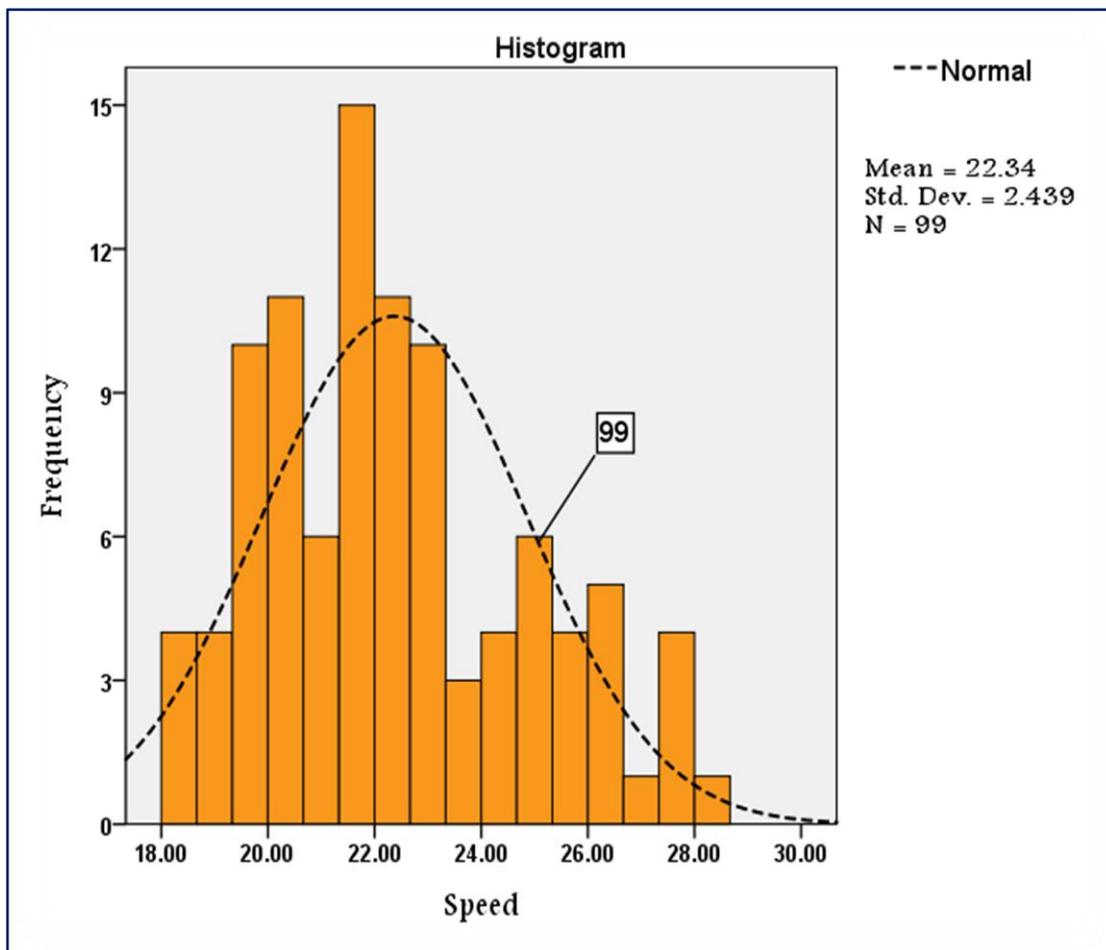
Figure(4-1) Normal Distribution of Speed According to SPSS Software

The vehicle's speed is entered into the VISSIM model via the vehicle speed distribution (In the case the mean value of the speed is entered without specifying the speed of each class, then VISSIM deals with the mean speed value with an increase and decrease of 10%).

In Figure (4-2). The horizontal axis represents the speed of the vehicle and the vertical axis represents the relative value in the range from (0.0 to 1.0). The curve shows five classes of speed starting from 18.3 to 28.3 in which 30 % of the vehicle speed between 20.3 and 22.3 km/h and 10% of the vehicle speed between 24.3 to 26.3 km/h. Correctly entering the speed of each class and its percentage will achieve the average speed value of 22.34 Km/h.
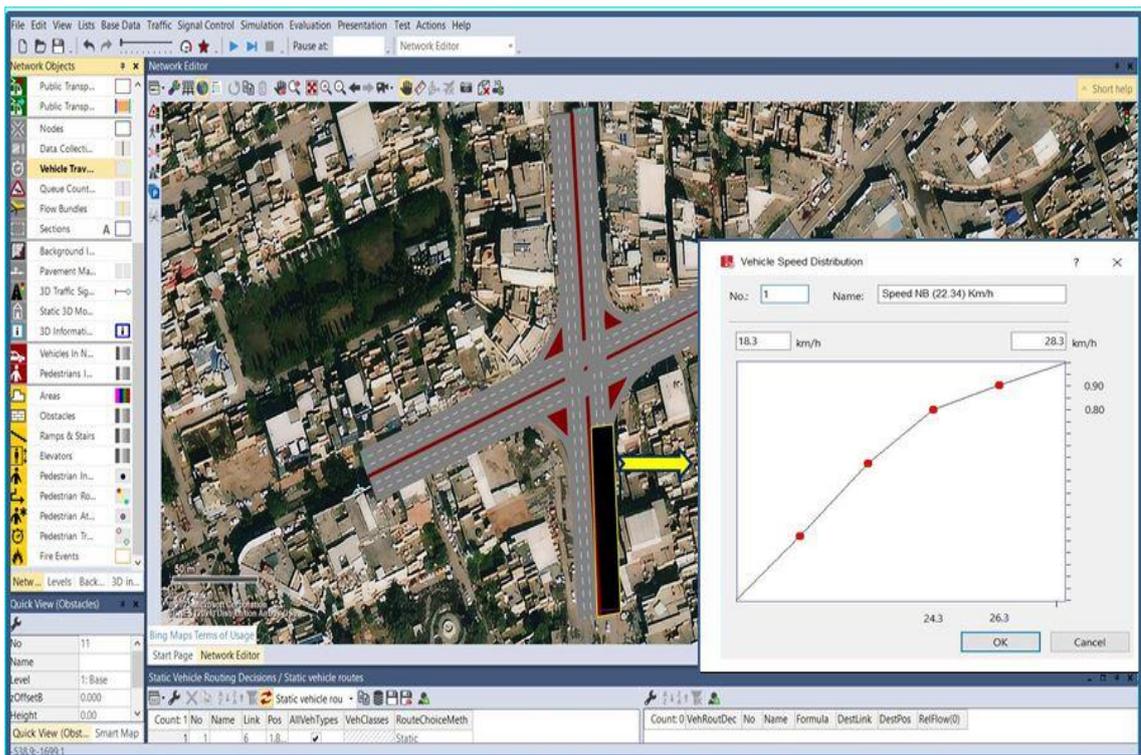
Figure (4-2) Vehicle Speed Distribution at NB for 40 St. Intersection

4.4 SSAM Analysis for Conflict Estimation

The trajectory files generated by the VISSIM simulation model can be transferred to SSAM for analysis and conflict data acquisition at each site. This role will be carried out through a series of steps that the SSAM model will perform.

Step 1: Optimal values of main safety indicators

In order to analyze conflicts and evaluate them properly, the optimal threshold values for surrogate safety indicators must be found: the TTC and the PET. SSAM model deals with TTC values starting from 0 and ending with a value of 5.5 seconds as a maximum. As for PET, it reaches a maximum of 10.5 seconds. Figure (4-3) shows the values of the conflict thresholds.
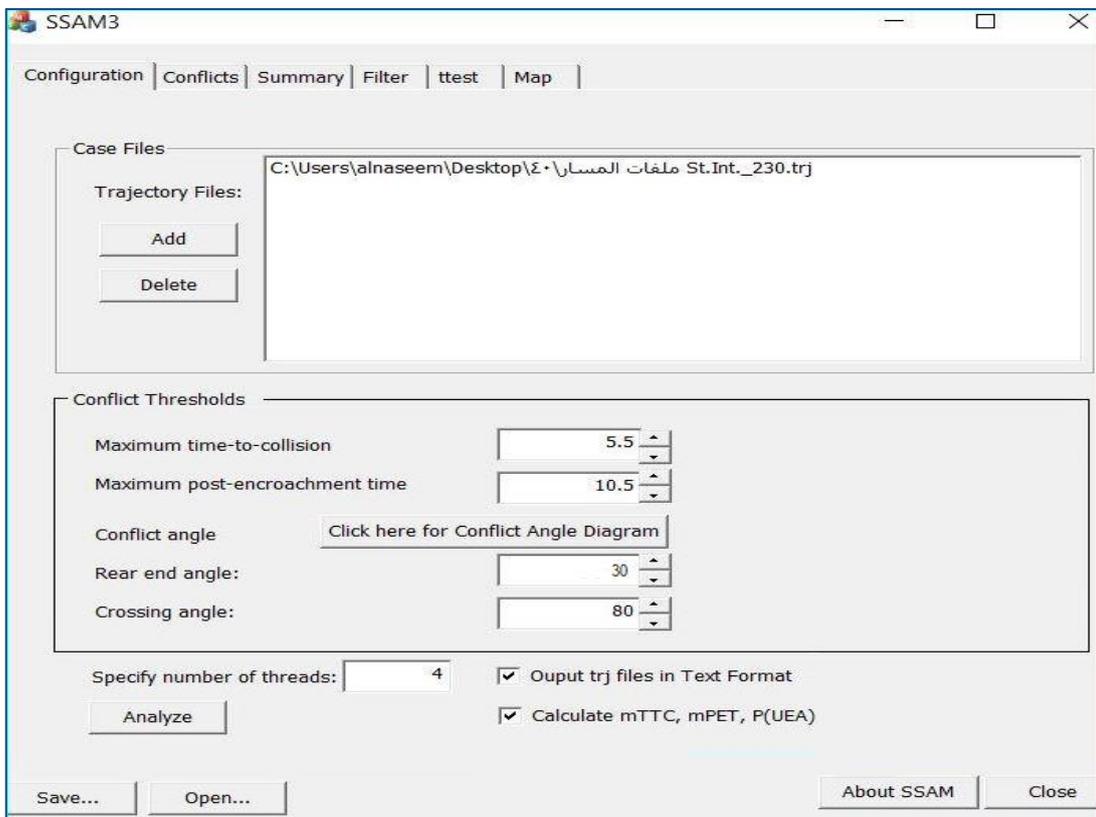
Figure (4-3) Screenshot for the SSAM Software Framework, Showing the Conflict Threshold Values

SSAM model uses the default values (TTC=1.5 s and PET= 5 s) depending on previous studies [86][87], which can be modulated by the user to get optimal values of the studied sites.

This is done by the available characteristic ''specify the number of threads'' in SSAM through Firstly, setting the threshold value for TTC by selecting the number of threads =1 and performing an analysis of the trajectory file, at each threshold of TTC the number of conflicts is recorded until getting the perfect TTC threshold corresponding to the least number of conflicts.

Secondly, after fixing the optimum value of TTC, (the number of threads was setting =2) and the PET thresholds are entered in each time with a value different from the previous one with increments of 0.1 seconds. Then the analysis is performed using both values (TTC optimal and the selected PET value).In turn, the number of conflicts is recorded in each analysis process until an optimum value of PET is obtained. Table (4-2) illustrates these values.

Table (4-2) Optimal Values Analyzed of the Main Safety Indicators for the Sites.

Intersection	No. of TTC	No. of PET	Range TTC Sec.	Range PET Sec.	Optimum TTC Sec.	Optimum PET Sec.
40 St.	55	105	0-5.5	0.-10.5	1.5	4.7
Bab-AL-Hussein	40	65	0.5-4.5	2 -8.5	1.6	5.0
Bab-AL-Mashhad	25	50	0.5-3.0	2.5-7.5	1.8	5.3

The default values for SSAM model are TTC = 1.5s and PET=5.0s

Figure (4-4) shows two curves, the first TTC and the second PET, and their relationship with the number of conflicts to extract the optimal values of TTC and PET at the 40 St. Intersection. The two curves show 11 values for each of TTC (within a range from 1 to 2) and PET (within a range from 4.2 to 5.2), out of 55 and 105 values, respectively.
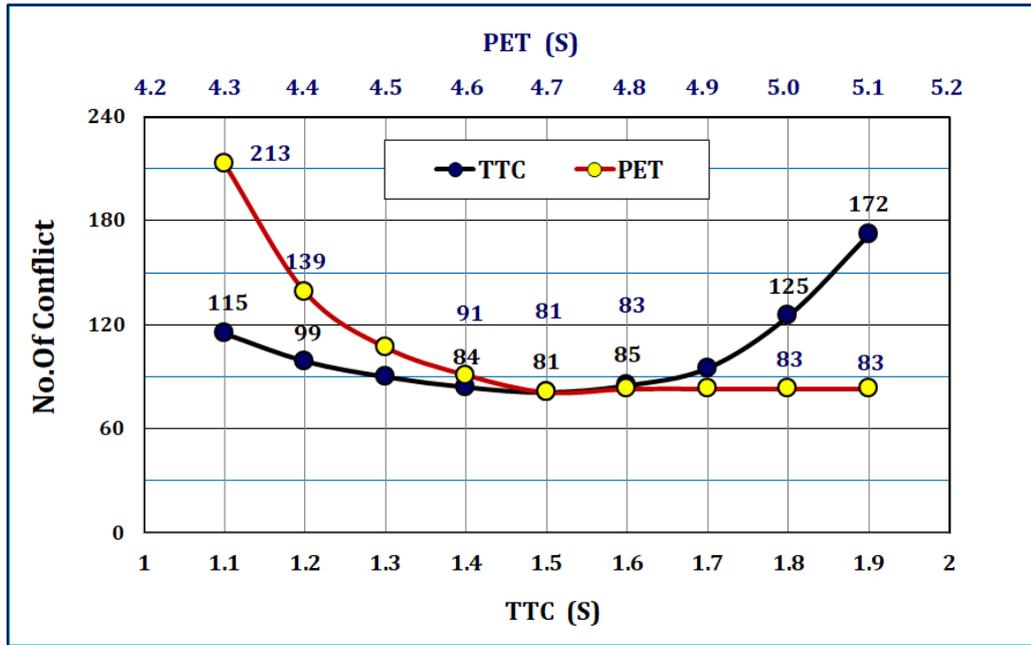
Figure (4-4) Relationship between Conflicts Number and Main Indicators Values for Safety at 40 St. Intersection

Step 2: Preliminary Outputs of the SSAM Analysis

To initiate the process of analyzing the trajectory files after setting the value of the (TTC) and (PET) thresholds. The trajectory files to be analyzed are added to the case files through a configuration tab. Then by just clicking "Analyze" the analysis process will start when the download of the trajectory files is completed.

The SSAM model processes the data from the trajectory file in order to elicit the conflict data information from these files. Processing the trajectory files sometimes need a long time, this depends on the size of the file created within the simulation model. Figure (4-5) shows the stages of the second step and the time taken to analyze the trajectory file for 40 St. Intersection.
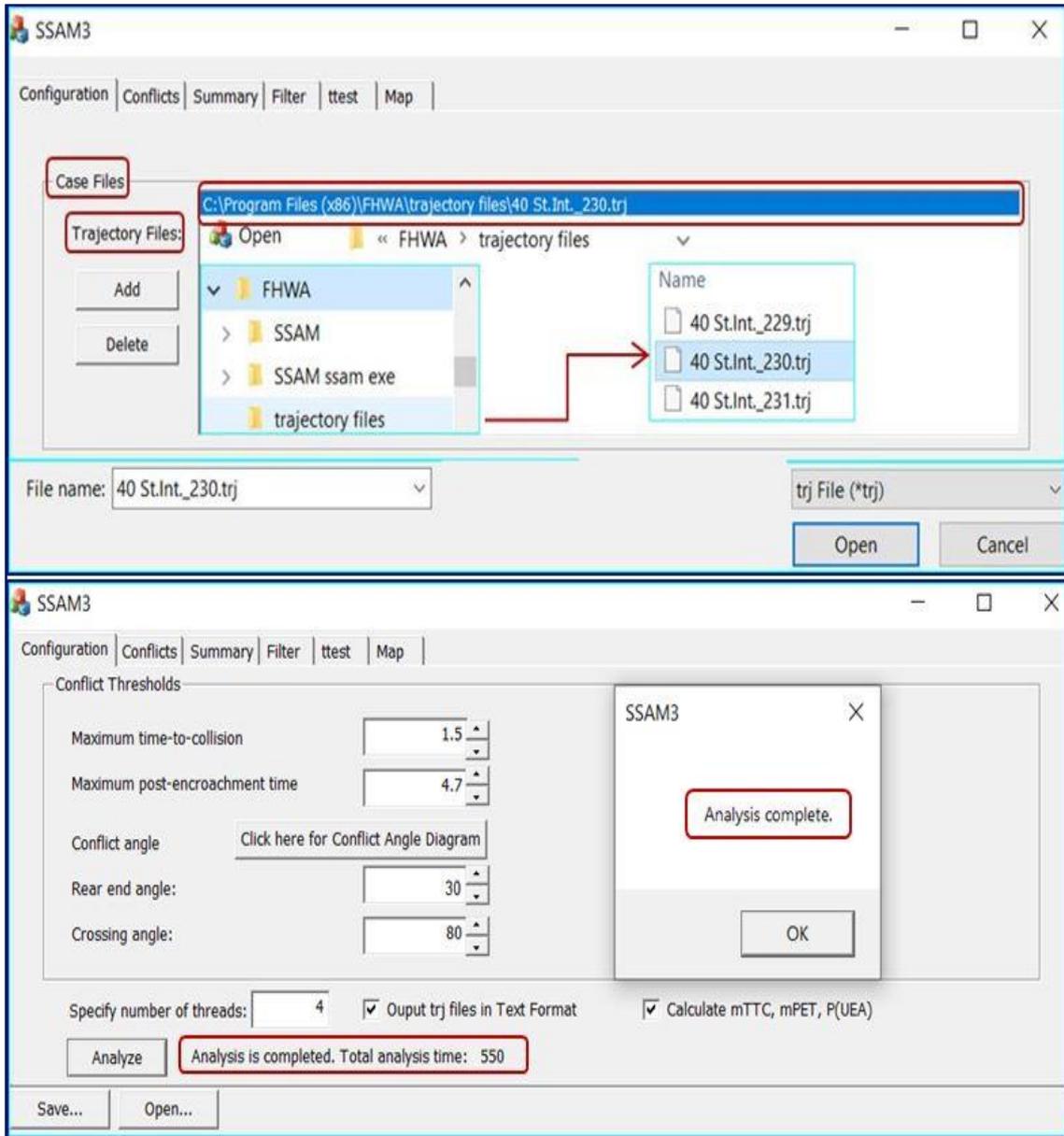
Figure (4-5) Configuration Tab Displaying Case Files

SSAM displays through the conflict tab a Table. In this table, each row symbolizes a conflict and every column appears specific information about that conflict as shown in Figure (4-6).

The results presented in this figure are preliminary results before applying the filter on them, it is worth noting that the SSAM model does not allow converting the units of the result values, but rather that the output units are identical to the units of the trj files that were created within VISSIM.

SSAM3 — □ ×

| Configuration | Conflicts | Summary | Filter | ttest | Map |

NO FILTER APPLIED

trjFile	tMinTTC	TTC	PET	MaxS	DeltaS	DR	MaxD	MaxDeltaV	ConflictAngle	ClockAngle	ConflictType
40 St.Int._230.trj	21.40	0.70	0.00	8.56	7.42	0.20	0.20	4.23	-5.75	6:11	rear end
40 St.Int._230.trj	23.10	1.20	0.40	7.08	2.07	-0.47	-3.51	1.03	-0.08	6:00	rear end
40 St.Int._230.trj	34.10	1.50	4.00	5.50	5.50	-2.86	-3.06	2.96	0.14	5:59	rear end
40 St.Int._230.trj	51.30	0.00	0.00	5.85	4.16	0.77	0.77	2.14	17.55	5:25	lane change
40 St.Int._230.trj	62.90	0.50	0.80	4.77	0.57	0.55	0.55	0.31	47.60	4:25	lane change
40 St.Int._230.trj	66.90	0.30	0.00	2.99	2.61	0.30	0.30	1.49	38.74	4:43	lane change
40 St.Int._230.trj	70.90	0.00	3.70	7.69	9.98	0.04	0.04	5.38	-106.27	9:33	crossing
40 St.Int._230.trj	75.50	0.80	0.80	6.56	3.08	-7.04	-7.12	1.69	24.98	5:10	lane change
40 St.Int._230.trj	83.70	0.10	2.40	0.56	0.14	0.00	0.00	0.08	10.00	5:40	rear end
40 St.Int._230.trj	87.90	0.70	0.50	2.29	1.78	0.00	0.00	0.92	-50.61	7:41	lane change
40 St.Int._230.trj	103.60	0.00	0.30	7.25	7.08	-0.02	-0.02	3.70	-73.66	8:27	lane change
40 St.Int._230.trj	110.30	0.80	1.60	7.29	2.35	-1.78	-1.78	1.21	-3.75	6:08	rear end
40 St.Int._230.trj	116.60	0.00	3.70	2.69	0.80	-2.38	-2.38	0.44	-47.73	7:35	lane change
40 St.Int._230.trj	117.70	1.30	2.00	3.11	3.01	-1.07	-5.87	1.60	34.81	4:50	lane change
40 St.Int._230.trj	123.30	0.00	0.00	7.78	8.86	0.04	0.04	4.85	-104.94	9:30	crossing
40 St.Int._230.trj	123.90	0.50	3.70	1.86	0.46	0.00	0.00	0.23	-57.63	7:55	lane change
40 St.Int._230.trj	124.70	0.30	3.70	7.84	9.52	0.04	0.04	5.06	-104.94	9:30	crossing
40 St.Int._230.trj	125.10	0.70	2.10	4.72	2.84	-7.17	-7.25	1.42	30.07	4:59	lane change
40 St.Int._230.trj	128.80	0.00	0.00	4.61	0.84	0.53	0.53	0.46	52.68	4:15	lane change
40 St.Int._230.trj	131.10	0.70	3.00	5.99	3.02	-1.34	-3.36	1.61	0.00	5:59	rear end
40 St.Int._230.trj	103.40	0.50	2.10	3.20	1.59	0.25	0.25	0.85	43.13	4:34	lane change
40 St.Int._230.trj	139.70	0.00	0.00	3.95	0.47	1.38	1.38	0.25	11.18	5:38	rear end
40 St.Int._230.trj	139.20	0.70	1.60	2.10	1.90	0.39	0.39	0.96	52.61	4:15	lane change
40 St.Int._230.trj	143.80	1.40	2.40	3.62	1.41	1.91	1.91	0.77	-44.68	7:29	lane change
40 St.Int._230.trj	161.10	0.00	0.00	8.54	3.00	0.79	0.79	1.55	-6.88	6:14	rear end
40 St.Int._230.trj	163.30	1.50	4.30	5.07	1.08	-0.58	-1.31	0.56	0.00	6:00	rear end
40 St.Int._230.trj	168.70	1.40	1.30	3.42	2.36	-3.50	-3.50	1.22	0.09	5:59	rear end
40 St.Int._230.trj	167.00	1.50	3.00	6.10	3.04	-1.40	-5.44	1.59	0.00	6:00	rear end
40 St.Int._230.trj	167.80	1.40	2.30	6.34	2.16	-0.44	-5.44	1.16	0.00	5:59	rear end
40 St.Int._230.trj	169.30	1.10	2.30	5.65	4.47	-0.72	-7.02	2.34	0.00	6:00	rear end
40 St.Int._230.trj	169.20	1.60	1.70	6.60	2.67	-0.42	-6.95	1.39	0.00	5:59	rear end
40 St.Int._230.trj	172.70	1.30	1.60	6.56	5.70	-0.95	-7.82	2.85	0.00	6:00	rear end
40 St.Int._230.trj	174.90	1.50	3.10	3.72	2.92	-1.82	-5.32	1.50	0.00	5:59	rear end
40 St.Int._230.trj	174.30	1.40	2.40	6.77	0.68	-1.00	-7.07	0.34	0.00	6:00	rear end
40 St.Int._230.trj	183.70	0.60	1.50	7.38	2.97	-7.97	-8.14	1.58	21.30	5:17	lane change
40 St.Int._230.trj	187.00	1.30	0.00	4.08	2.28	0.65	0.65	1.17	-11.18	6:22	rear end
40 St.Int._230.trj	190.80	1.50	1.70	7.76	8.71	-0.22	-0.22	4.96	-106.27	9:33	crossing
40 St.Int._230.trj	191.30	0.00	0.00	7.20	9.06	-0.22	-0.22	5.16	-106.27	9:33	crossing

Export to csv file...

Save... | Open... | About SSAM | Close

Figure (4-6) Screen Capture for SSAM with Conflicts Details

SSAM provides a summary table of the conflicts. The summary table consists of two parts. The first provides statistical information include (Minimum, Maximum, Mean, and Variance) for SSAM-measure (TTC, PET, MaxS, MaxD, DeltaS, and MaxDeltaV), which are described in (Chapter 2 Article 2.9.3). The second part of the summary table displays the total number of conflicts for the analyzed trj file and the conflicts number of each type of conflicts as shown in Figure (4-7).
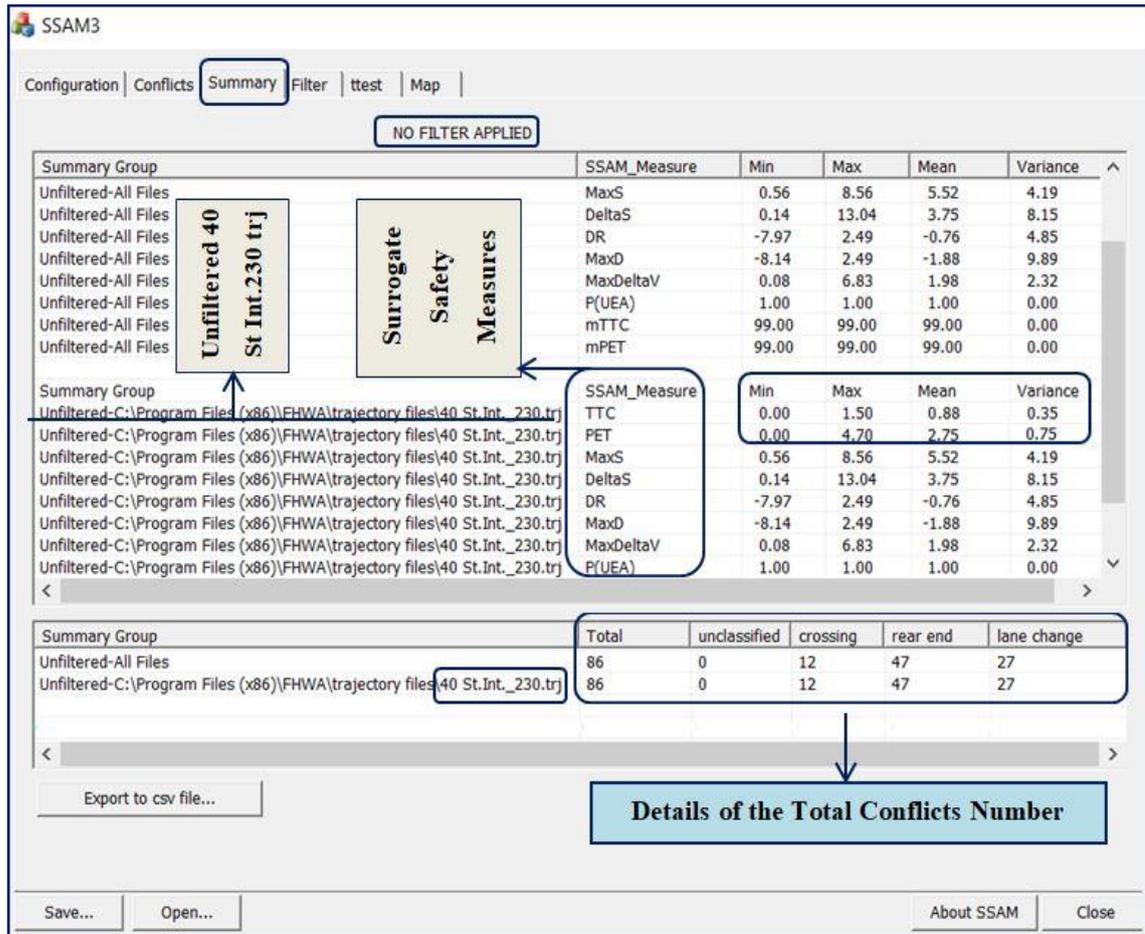
Figure (4-7) SSAM Screen to Display Statistical Summary of Conflict, Before Applied Filter

Step 3: Apply Filtering for Conflicts Results

This step shows how to use the filter for SSAM results in two stages:-

A- Filter the Results in the Sense of Excluding the Illogical

SSAM Software includes a result filtering tool to remove some irrelevant results or due to simulation error results. The zero-threshold values for both TTC and PET has been removed because these zero values represent crashes and do not represent the analysis required, which is the conflict (near to collision).

Accordingly, a minimum value of TTC and PET not less than 0.1 was used instead of the zero values. After pressing the Apply (filter command), the results appeared again in a summary tab with statistical

information and conflicts number different than before (before filtering); for example, the total conflicts decreased from 86 to 79 and rear-end conflicts from 47 to 43. Figure (4-8) shows the results after filtering the suspicious results.
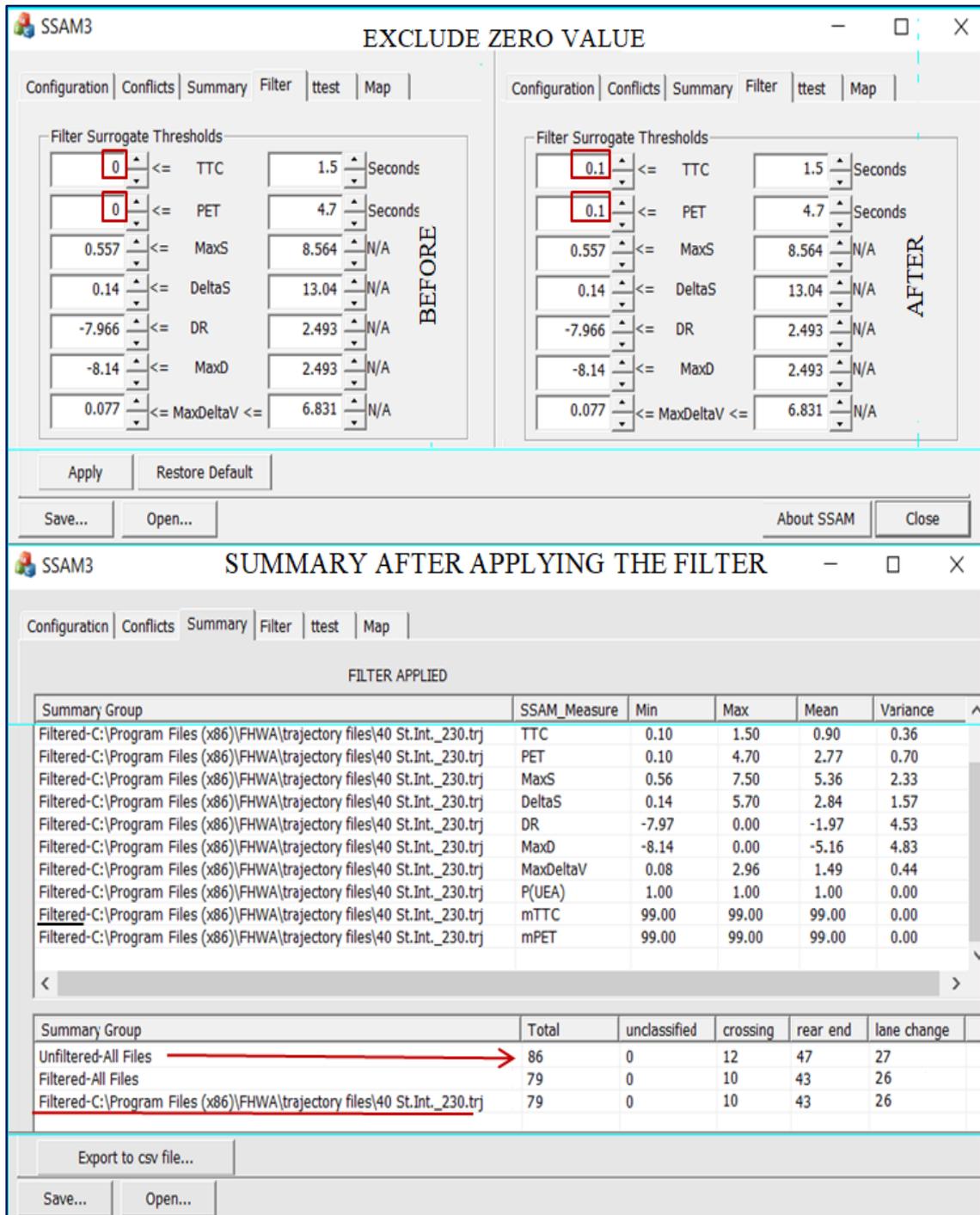
Figure (4-8) SSAM Screen for Statistical Summary of Conflicts After Applied Filter to Exclude Illogical Results.

B-Filter Results in the Sense of Sorting

The many details of conflict data maintained and displayed as a one-block lead to the difficulty of evaluating a section or part of a site, so it requires sorting. Results have been sorted by filter according to the following criteria.

- ▪ **Types of Conflicts**

Through this filter, it is possible to display (one type of conflict, more than one type of conflict, and all types of conflicts) as shown in Figure (4-9).
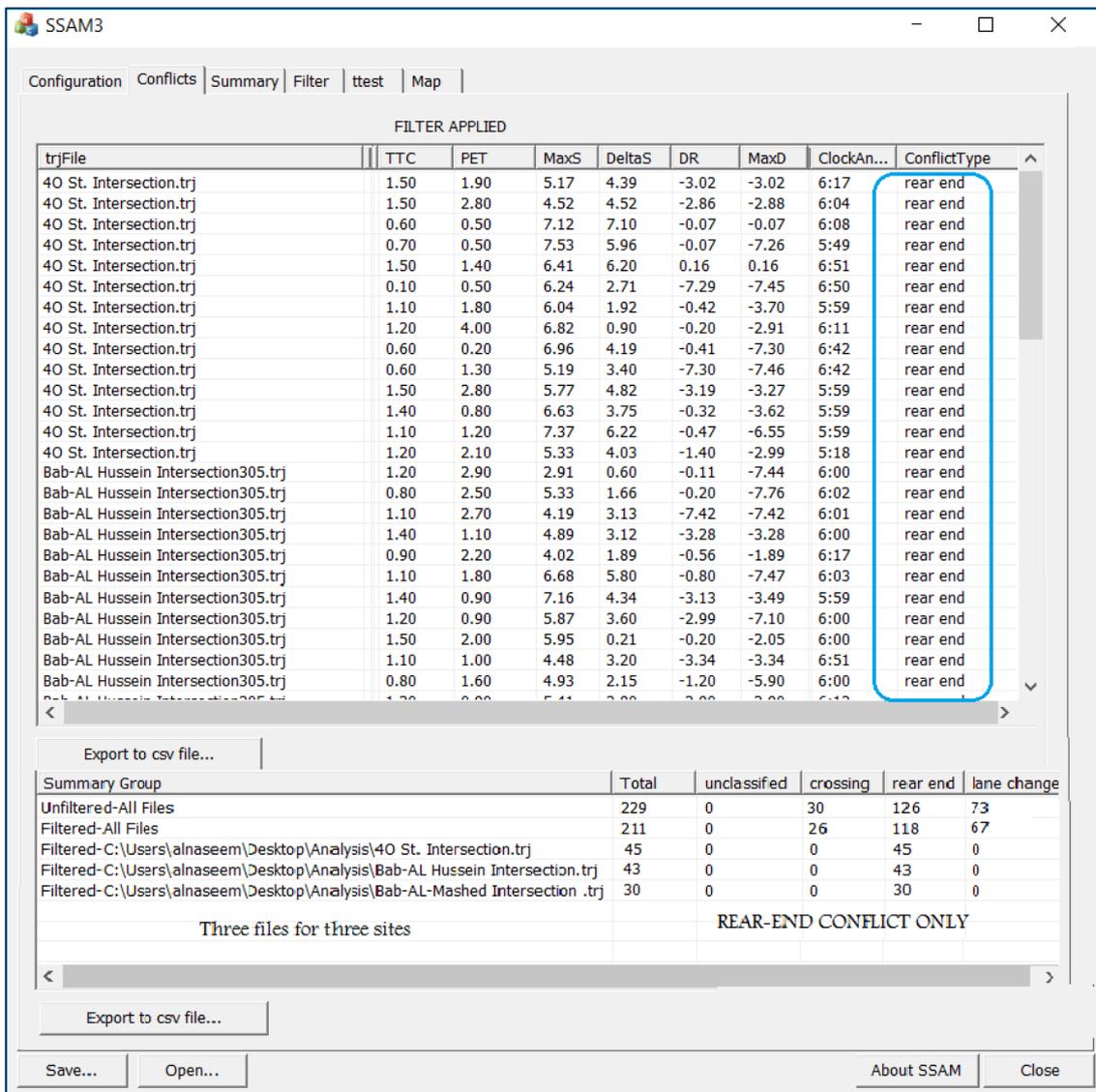
Figure (4-9) Screenshot Showing the Type of Conflicts That were Filtered

It displays the number of rear-end conflicts only, (45, 43, and 30) in each of the intersections (Street 40, Bab Al-Hussein, Bab Al-Mashhad) respectively. Other types of conflicts were withheld (given zero values to the rest of the types of conflicts).

▪ **Filter Links**

Often the evaluator needs to know the evaluation of each section of the site's network as well as the evaluation of the entire site. Therefore, Filter links most important feature of the filter by which the details of the conflicts can be shown for each link (approach) to know where the most number of conflicts are concentrated and where their danger lies.

More than one link can be combined to show their details and display conflicts of an entire intersection. Figure (4-10) shows the number of conflicts for two legs from four legs at Bab Al-Mashhad Intersection.
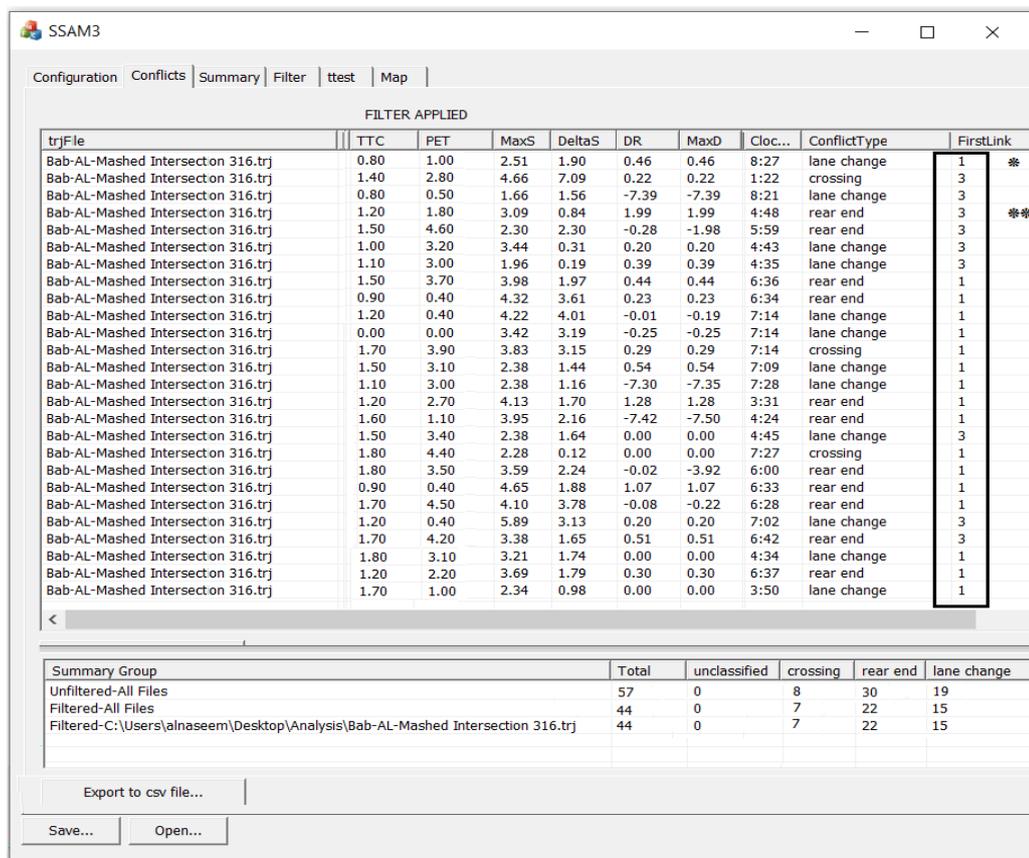
Figure (4-10) Screenshot Showing Conflicts at (1&3) Links Filtered

The analysis of the trj file shown in this figure showed that the total number of conflicts in the entire site amounted to (57) conflicts distributed as (8) crossing, (30) rear-end, and (19) lane change. The share of the northern and southern approaches of them was 44 (out of 57) total conflicts, distributed (7) crossing, (22) The rear end, and (15) lane change. In short, were it not for this feature (filter links), it would not have been possible to evaluate each approach of the intersection separately.

- **Filter Site File**

In addition, SSAM can filter one site from a group of sites through filter trj files. Figure (4-11) shows part/filter of conflicts for (two types of conflicts are crossing and lane change, two links are 2 (EB) and 3 (SB), and one trj file is 40 St.Int.230.
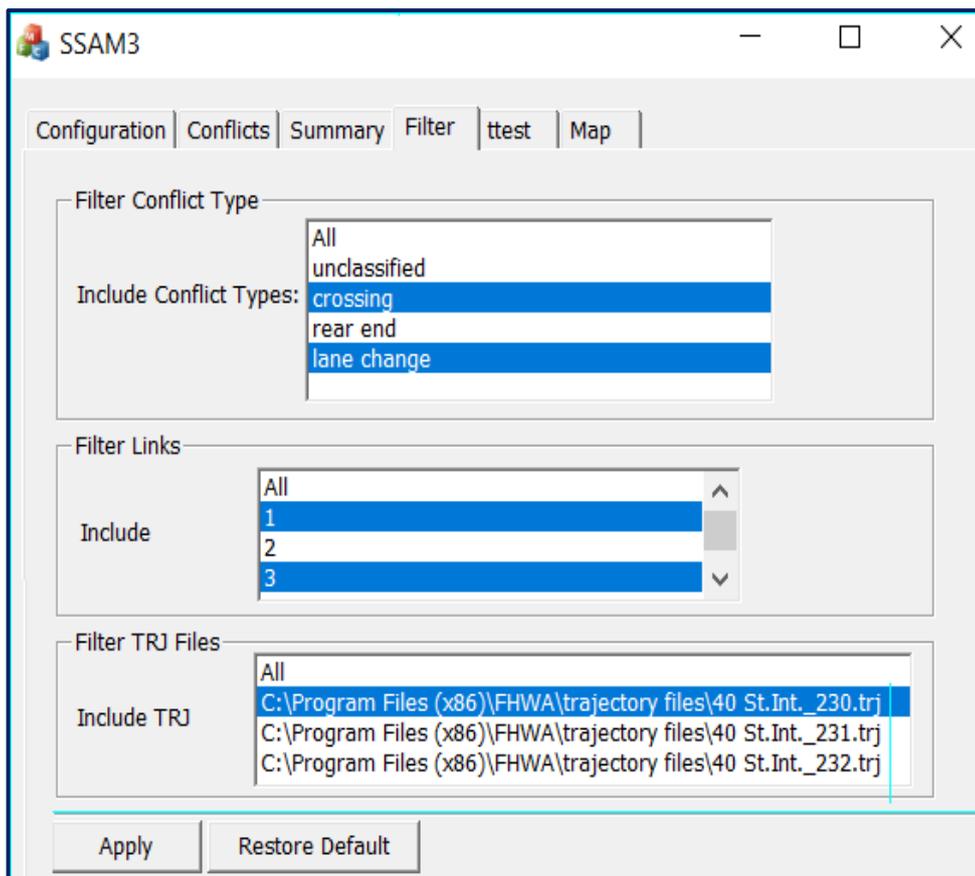
Figure (4-11) Screenshot of the SSAM Model Showing Filter Procedure for One of the Trj Files at 40 St. Intersection

Step 4: Determination Type of Conflicts

SSAM software relies on the angle between every pair of conflicting vehicles calculated in the VISSIM simulation model to classify the conflict; The conflict is classified as [63].

- Crossing: if { conflict angle > 85 degree }.
- Rear-end: if { conflict angle < 30 degree }.
- Lane-change: if { $30° \leq$ conflict angle $\leq 85°$ }.
- Unclassified: if { Conflict angle unknown }.

Figure (4-12) shows the classification of conflicts according to the angle of conflict.
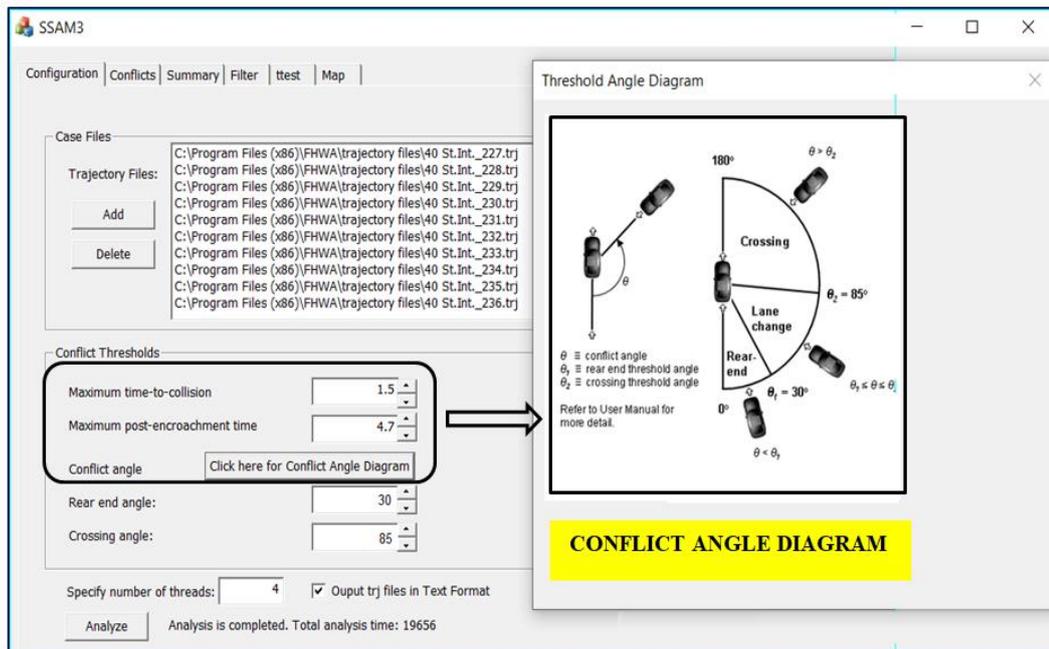
Figure (4-12) Capture of SSAM Screen Illustrated Conflict Angle Diagram

The rear end conflict often occurs when the two vehicles are on the same link and the same lane. The lane change conflict occurs in the same link when the vehicle's path changes from one lane to another, while the crossing conflict occurs when the vehicles are on different links on a vertical or semi-vertical angle. Figure (4-13) illustrates the conflicts were recorded by VISSIM and their types were interpreted by SSAM.
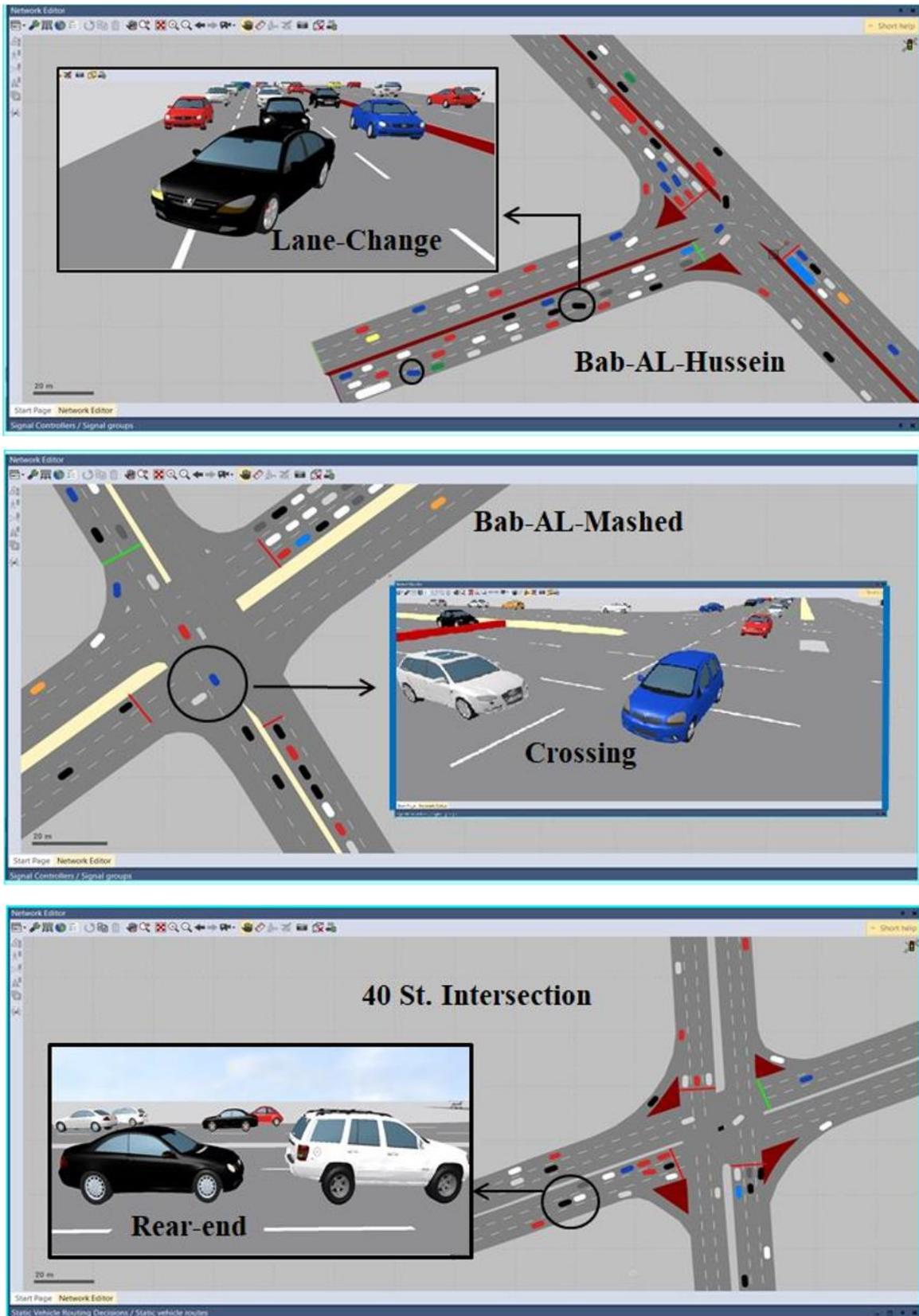
Figure (4-13) 3D Snapshots for the VISSIM Highlights the Types of Conflicts at the Intersection Sites

Step 5: Determination Conflicts Severity

There are different severity levels for conflicts. Severity levels were categorized according to various groups of (TTC) values starting from zero to greater than 1.5; zero refers to crashes, values > 1.5 refers to low risk between the conflicting vehicles. SSAM can display conflicts on a map of the type of conflicts and the severity. Figure (4-14) indicates a map of one of the simulated trj files showing the severity of the conflicts at the 40 St. Intersection.
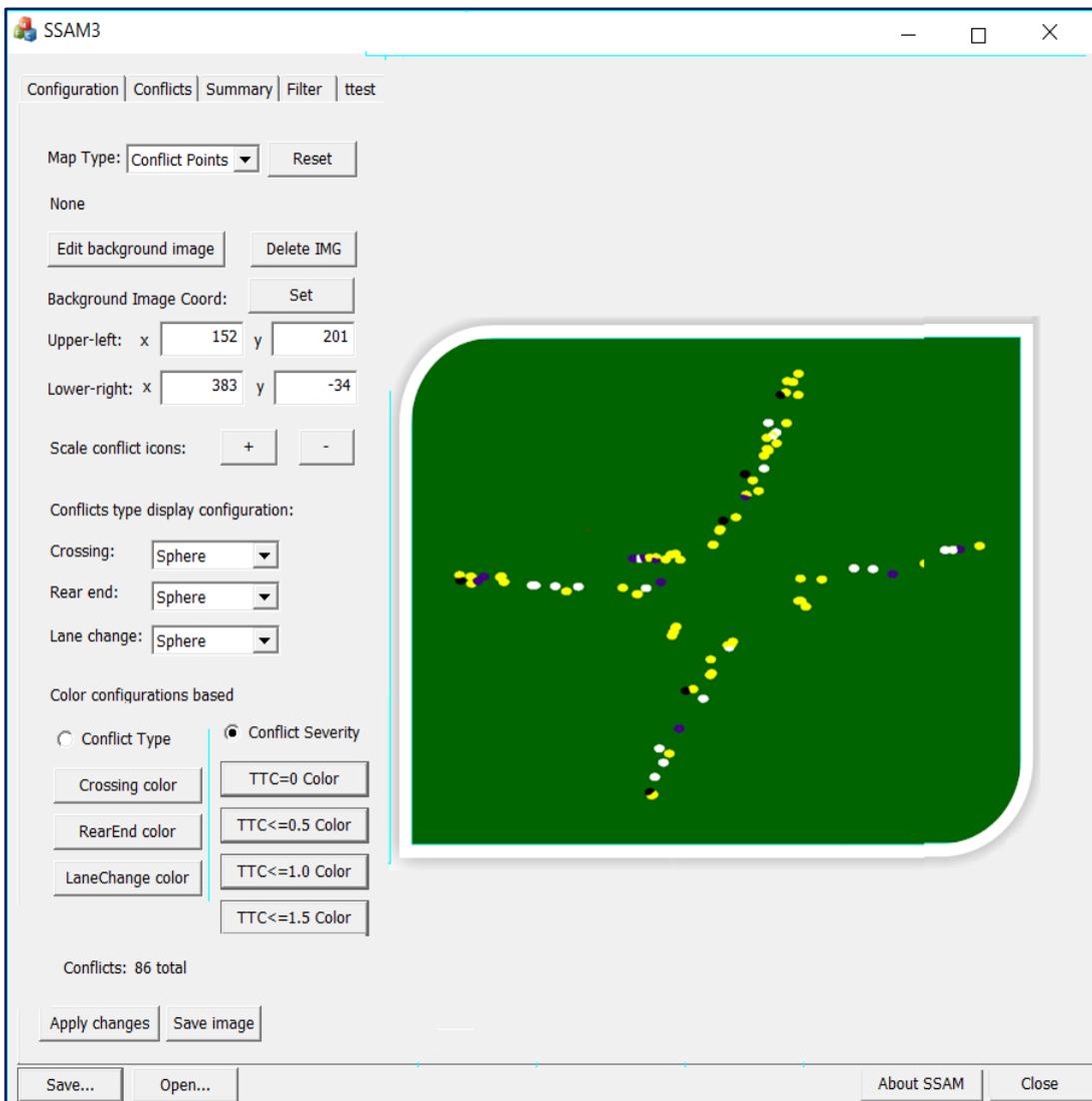
Figure (4-14) SSAM Screen Showing A Map of the Severity of Conflicts

4.5 SSAM Output

If the five steps in paragraphs mentioned (4-2) are followed, the results of the conflict analysis after calibrating the simulation software and filtering it by SSAM software are following:

4.5.1 Results of Surrogate Safety Indicators

Surrogate safety indicators for a part of one file (25 out of 83[*] conflicts) analyzed by SSAM Software are shown in the Table(4-3).

Table (4-3) SSAM Analyses of Surrogate Safety Measures of Conflicts at (40 St.) intersection

Trj File	TTC	PET	Max S	Delta S	DR	Max D	Max Delta v	Conflict Angle	Conflict Type
40 St.232	1.20	1.40	8.44	8.19	1.20	-0.20	4.67	-6.17	RE
40 St.232	0.40	2.10	6.56	2.53	0.40	-8.03	1.26	-20.67	LC
40 St.232	0.40	3.20	4.93	2.21	0.40	-7.43	1.21	25.54	LC
40 St.232	1.50	2.80	5.10	5.10	1.50	-2.69	2.83	0.36	RE
40 St.232	1.20	2.60	7.34	4.29	1.20	-3.03	2.15	0.06	RE
40 St.232	0.60	2.50	6.31	2.84	0.60	-7.23	1.46	-21.71	LC
40 St.232	1.40	2.40	4.35	.76	1.40	-7.08	0.42	0.55	RE
40 St.232	1.10	1.90	5.33	1.54	1.10	-2.54	0.82	0.78	RE
40 St.232	1.30	2.00	8.17	4.68	1.30	-6.17	2.34	-0.03	RE
40 St.232	1.30	2.60	7.02	4.74	1.30	-7.06	2.60	0.22	RE
40 St.232	1.40	2.40	8.74	2.24	1.40	-3.47	1.28	3.64	RE
40 St.232	1.10	3.20	6.48	6.38	1.10	-6.81	3.19	-16.1	LC
40 St.232	1.20	2.50	7.92	3.62	1.20	-6.62	1.95	18.02	LC
40 St.232	0.80	2.30	5.37	0.90	0.80	-6.64	0.47	10.3	LC
40 St.232	1.30	2.10	6.63	2.60	1.30	-7.8	1.44	0.23	RE
40 St.232	1.20	2.50	6.42	0.43	1.20	-7.47	0.22	11.22	RE
40 St.232	0.60	2.20	4.18	0.31	0.60	0.29	0.24	20.38	RE
40 St.232	0.10	1.80	3.34	0.02	0.10	0.40	0.02	7.01	RE
40 St.232	0.80	2.20	7.47	6.87	0.80	-2.87	3.76	-23.56	LC
40 St.232	1.50	4.70	4.13	1.87	1.50	-6.38	1.07	33.12	LC
40 St.232	0.30	3.30	6.37	2.74	0.30	-7.39	1.56	-14.62	LC
40 St.232	0.70	2.60	8.89	5.52	0.70	0.20	3.02	-4.38	RE
40 St.232	0.80	2.80	7.21	9.47	0.80	-0.22	4.73	-107.25	C
40 St.232	1.00	1.80	7.44	10.15	1.00	-0.22	5.79	89.64	C
40 St.232	0.90	2.40	5.37	0.90	0.80	-6.64	0.47	5.25	RE

Rear End= RE, Lane Change= LC, Crossing= C   * Rest of the results in Appendix D

Table (D-1) in Appendix D presents the complement of the analysis for (40 St.232) trj file and the two Tables (D-2), (D-3) present the full results for Bab Al-Hussein and Bab Al-Mashhad intersections trj file, respectively.

4.5.2 Summary Results

Tables (4-4) to (4-6) present a summary of the statistical data for the SSAM measure, in addition to a summary of the total conflicts for 10 trj files analyzed for each site.

Table (4-4) A Summary of Statistical Data on the SSAM Measures and Total Conflicts (40 St.)

Summary Files	SSAM-Measure	Min	Max	Mean	Variance
Filtered 10 Trajectories Files (40 St. Int.) N=807	TTC	0.10	1.50	0.86	0.22
	PET	0.10	4.70	2.34	0.72
	Max S	0.56	8.89	5.83	2.77
	Delta S	0.02	13.13	4.03	2.93
	DR	-8.09	1.50	0.30	0.24
	Max D	-8.15	0.44	-4.75	4.80
	Max Delta V	0.02	7.18	0.26	2.64

Summary Files	N	Total	Crossing	Rear end	Lane change
Unfiltered (Mean) 10 Files	879	88	13	47	28
Filtered (Mean) 10 Files	807	81	11	45	25

N: Represents the number of conflicts for 10 trj files.

Table (4-5) A Summary of Statistical Data on the SSAM Measures and Total Conflicts (Bab-AL-Hussein)

Summary Files	SSAM-Measure	Min	Max	Mean	Variance
Filtered 10 Trajectories Files Bab-AL-Hussein N=730	TTC	0.10	1.60	0.82	0.16
	PET	0.40	4.70	2.26	0.83
	Max S	0.92	8.08	5.23	3.02
	Delta S	0.02	7.19	3.60	2.62
	DR	-7.91	0.78	-2.85	6.47
	Max D	-8.33	-0.02	-4.90	6.09
	Max Delta V	0.01	4.76	1.52	0.97

Summary Files	N	Total	Crossing	Rear end	Lane change
Unfiltered (Mean) 10 Files	790	79	8	46	25
Filtered (Mean) 10 Files	730	73	7	43	23

Table (4-6) A Summary of Statistical Data on the SSAM Measures and Total Conflicts (Bab-AL-Mashhad)

Summary Files	SSAM-Measure	Min	Max	Mean	Variance
Filtered 10 Trajectories Files Bab-AL-Mashhad N=571	TTC	0.10	1.80	1.23	0.14
	PET	0.30	5.30	2.46	0.92
	Max S	0.28	5.38	3.25	1.14
	Delta S	0.03	5.41	2.26	1.55
	DR	-7.39	3.03	-2.85	6.47
	Max D	-7.59	3.03	-1.82	6.35
	Max Delta V	0.02	2.58	1.24	0.39

Summary Files	N	Total	Crossing	Rear end	Lane change
Unfiltered (Mean) 10 Files	619	62	9	33	20
Filtered (Mean) 10 Files	571	57	8	30	19

4.5.3 TTC Results as a Tool to Evaluate Safety

The method for assessing safety by a simulation approach is based on the severity of conflicts using Time To Collisions (TTC). SSAM determines the severity of conflicts through TTC values as stated in step 5 of SSAM's methodology to conflict analysis(SSAM Manual). SSAM's conflict severity rating also corresponds to the conflict severity ratings developed by (Syed and Zain) [22]. Table (4-7) shows the evaluation of conflict severity accordingly different ranges of TTC values.

Table (4-7) Conflicts Risk Correlating with (TTC) Values Ranges [22]

Time To Collision (TTC) Range	Risk Of Conflict (ROC)
1.5< TTC <2 s	Low Risk
1< TTC <1.5 s	Moderate Risk
0< TTC <1 s	High Risk

With the feature of filtering the links available in SSAM(step 3 B), the evaluation of the severity of each approach was specified for the intersections, in addition to the evaluation of the entire intersection, as shown in Table (4-8).

Table (4-8) Conflicts Evaluation at Each Approach of Intersections Sites

Intersection	Approach	(No. of Conflict/ hr) / App.			$THTC_{APP}$	TTC_{APP}	$ROCR_{APP}$	$THTC_I$	TTC_I	$ROCR_I$
		RE	LC	C						
40 St.	NB	12	8	3	23	0.80	HR	81	**0.86**	HR
	EB	6	5	3	14	1.03	MR			
	SB	11	6	2	19	0.93	HR			
	WB	15	7	3	25	0.77	HR			
Bab-AL Mashhad	NB	12	8	4	24	0.92	HR	57	**1.23**	MR
	EB	5	3	1	9	1.47	MR			
	SB	10	7	3	20	0.98	HR			
	WB	3	0	1	4	1.8	LR			
Bab-AL Hussein	NB	16	8	2	26	0.77	HR	73	**0.82**	HR
	EB	19	10	4	33	0.74	HR			
	WB	9	4	1	14	1.11	MR			

$THTC_{(APP, I)}$: Total hourly traffic conflicts at approach and intersection respectively.
$ROCR_{(APP, I)}$: Risk of collision rating at approach and intersection respectively.
$TTC_{(APP, I)}$: Time to collision at approach and intersection respectively.
HR,MR,LR: Represents **High risk** , **Moderate risk** and **Low risk** respectively.

Evaluation traffic safety at the signalized intersections showed 40 St and Bab Al-Hussein intersections have a high-risk TTCI value less than one (0.86 and 0.82) respectively, while the Bab Al-Mashhad intersection was evaluated as a moderate-risk intersection. TTC_I is limited between two values greater than (1) and less than (1. 5).

The results also showed that the traffic safety evaluation of the intersection approaches ranged between high risk (the largest percentage of approaches) and moderate risk (the lowest percentage of approaches) except the safety evaluation of the EB of Bab Al Mashhad intersection, which was evaluated as a low-risk approach (TTC_{APP} = 1.8) This is due to two main reasons:

- The approach is witnessing a very low traffic volume
- There are no lane change conflicts between vehicles at this approach, and this explains the appearance of the value (0) for lane

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change conflicts in the Table (4-8), which was caused by the right lane being closed for security reasons (Prison site) and remaining one lane for traffic movement.

4.5.4 Conflicts Results on Map

Arc-GIS (version 10.5) software was used due to the shortcomings of the SSAM software in displaying conflict map on the site map, although the SSAM displays a conflicts map with massive accuracy for coordinates (x, y), as shown in Figure (4-15), but does not capture site layout by SSAM.
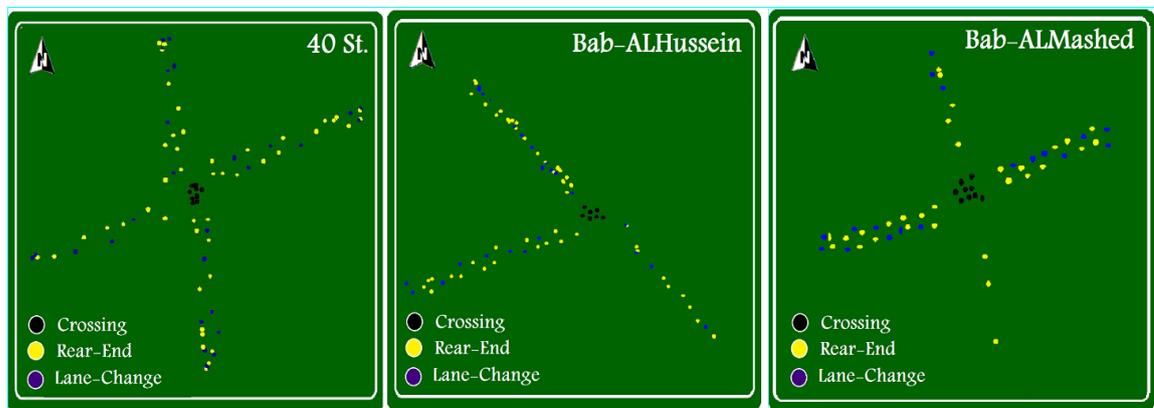
Figure (4-15) Conflicts Results from SSAM Model in the Form of Conflict Points

Arc-GIS software can display the conflicts on the site map (Base Map), the spatial analysis of the conflicts was used and shown through a triple linking between programs used (VISSIM, SSAM, and Arc-GIS) with the help of the Excel software.

The triple linkage by VISSIM began to determine trajectories vehicles and the coordinates of the movement, SSAM took over the identification of the conflicts then turning the file into an Arc Map to display the spatial analysis of the conflicts. Figures (4-16) to (4-18) illustrate the kernel density tool for the conflicts in the three intersections, also figures show the extreme accuracy in projecting conflicts density on a base map of the studied sites.
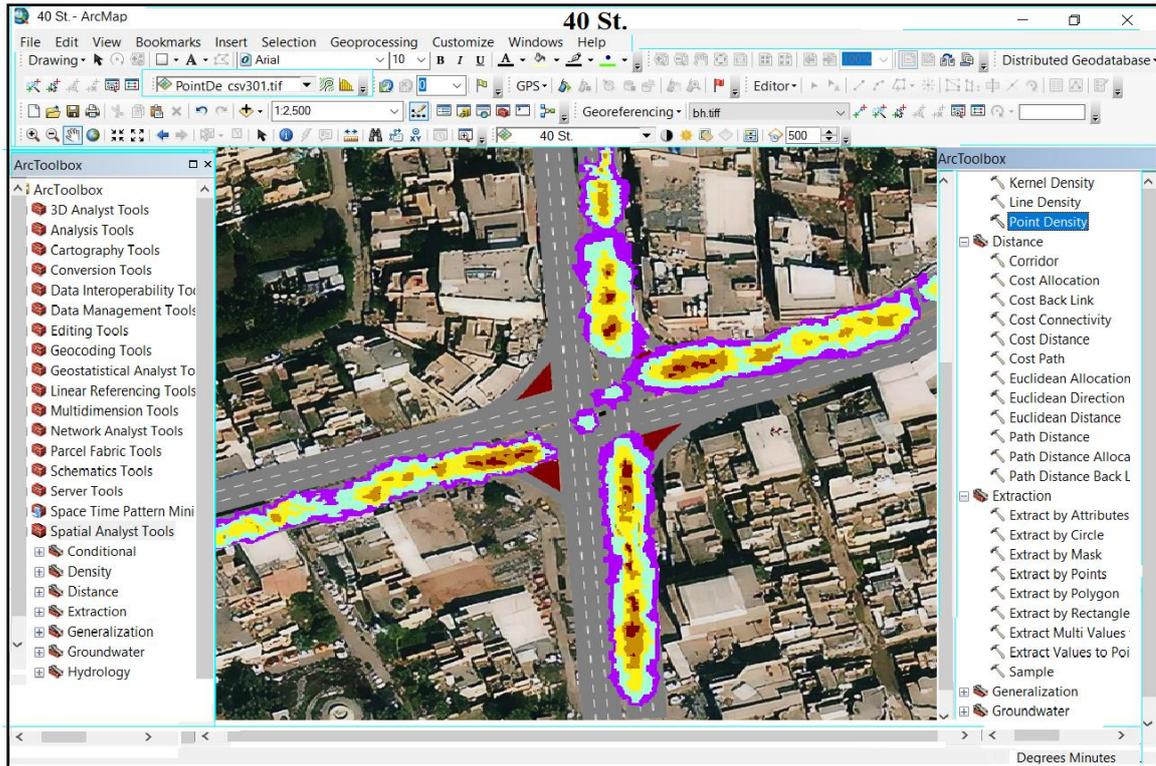
Figure (4-16) Screenshots of Arc-GIS Software, Showing Kernel-Density Tools of Conflicts
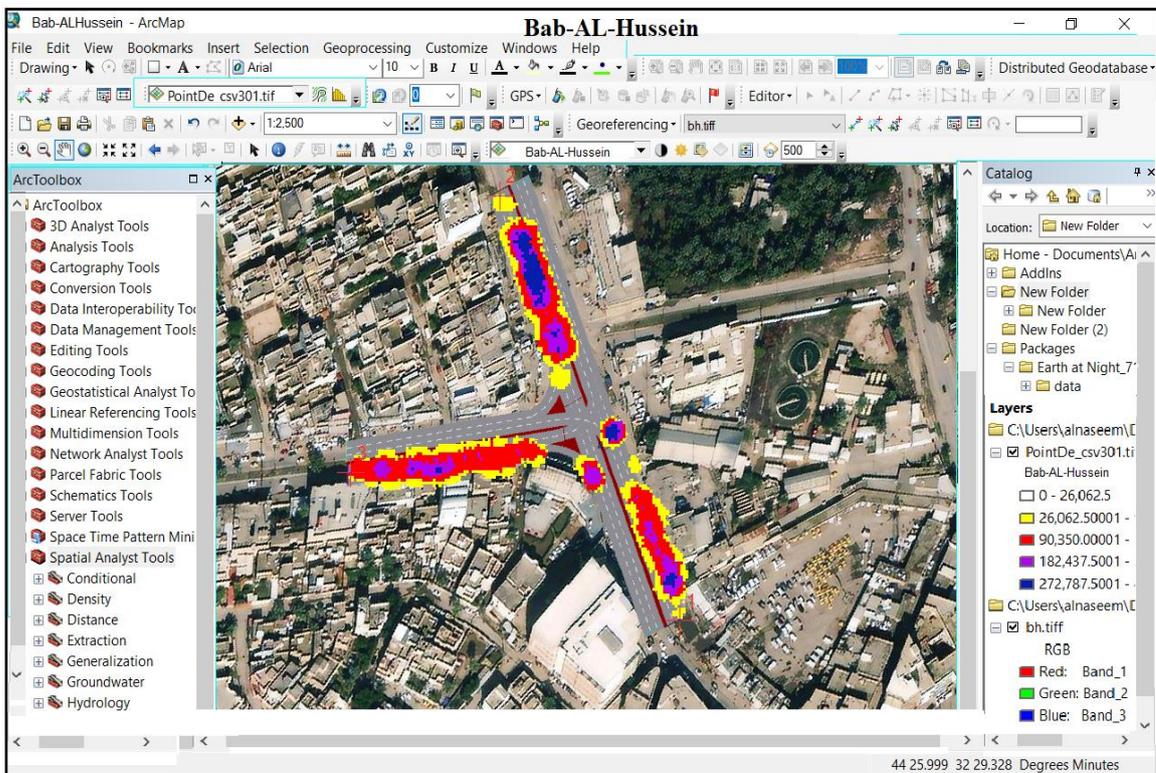
Figure (4-17) Screenshots of Arc-GIS Software, Showing Kernel-Density Tools of Conflicts
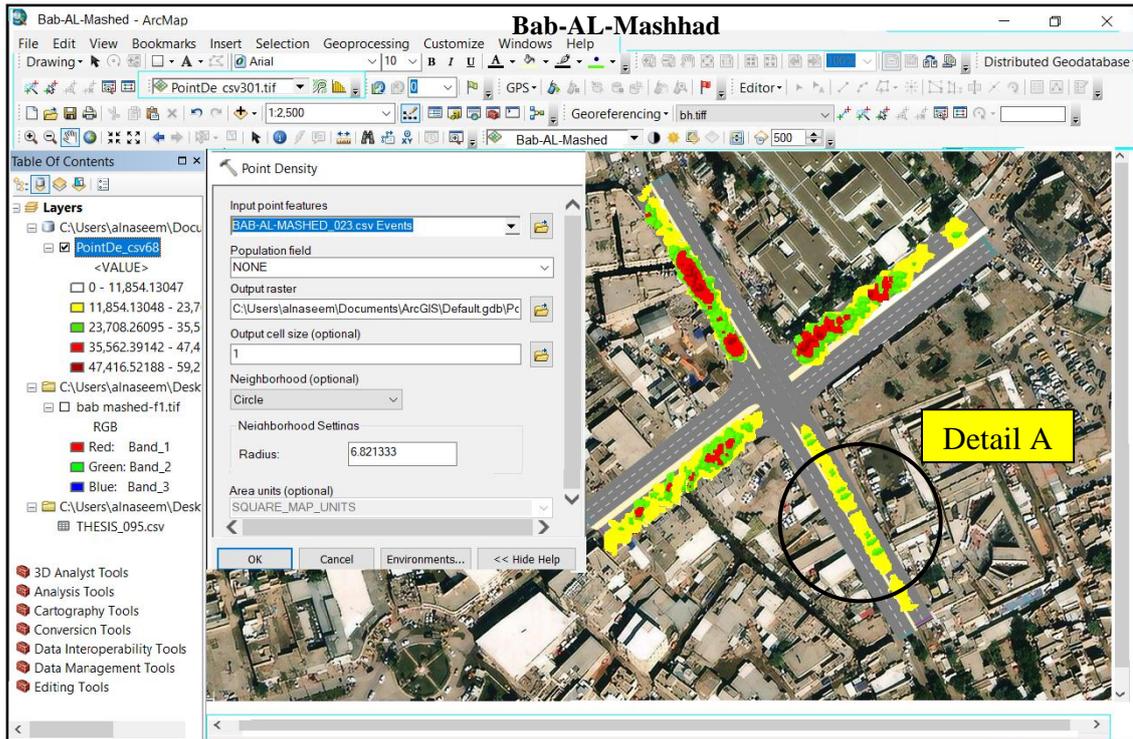
Figure (4-18) Screenshots of Arc-GIS Software, Showing Kernel-Density Tools of Conflicts

Figure (4-19) shows (A) details in the this Figure, which includes the concentration of Kernel-Density in one lane out of two lanes of which the right lane of the eastern approach was closed (parallel to Hilla prison) to the intersection of Bab al-Mashhad.

Figure (4-19) Screenshot Highlighting the Kernel -Density of the WB for Bab Al Mashhad Intersection

4.6 Spatial Conflict Heat Maps

In addition to the conflict point map in SSAM, a Spatial conflict heat map diagram was presented from all simulation scenarios to investigate the spatial distribution and severity of conflicts. Distinctive features of heat maps are a visual means that depicts the spatial characteristics of conflict effects and is suitable for decision-making by the analyst about their treatment. To plot heat maps, Time To Collision was adopted. Figure (4-20) displays heat maps that represent the spatial severity for all types of conflicts at (0 <TTC <2) thresholds.

Symbol / TTC Value	1 > 0.0–0.50	2 0.50–1.00	3 1.00–1.50	4 1.50–<2.0
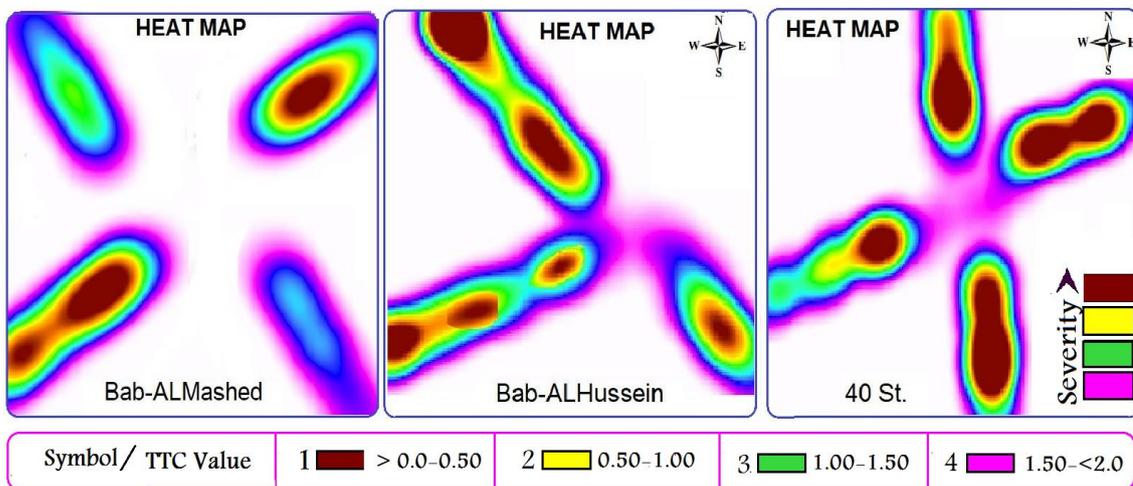
Figure (4-20) Spatial Conflict Severity in the Form of Heat Maps by Arc-GIS Tools

The density and severity of the conflict occur at the beginning of the stopping line and sometimes at the end of the queue. This explains the many conflicts in these areas. In the first area, the driver of the vehicle tries to cross the intersection area before the red light starts whereas in the second area, tries to approach more than the stopping line, so the driver maneuvers a lot to reach his aspiration (approaching from the stop line) In addition, its speed is rather high before it stops at the end of the queue, In both cases, too many maneuvers lead to the occurrence the largest number of conflicts.

The risk levels for intersections zones were classified into 4 different levels when applying heat map by defining interval data categorization method in (Arc-GIS) tools as shown in Table (4-9).

Table (4-9) Classification Severity Levels of a Zone at Intersections.

Severity Level	Zones Evaluation	Level color gradations for each zone
1	Very high risk	
2	High risk	
3	Moderate risk	
4	Low risk	
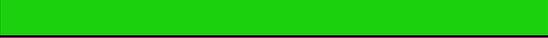
4.7 Calibrating and Validating Simulation in Safety Estimation

4.7.1 Calibrating VISSIM Simulation Model

The methodology of calibration is based on matching driving behavior measured in the field with a micro-simulation approach. VISSIM depends on a "psycho-physical car-following" model and the perception thresholds of driver behavior[51].

It is important to calibrate driving behavior parameters and to identify an acceptable range for selected parameters. Traffic simulation models include different default parameters that represent traffic characteristics, including driver behavior parameters, which are the main component of any traffic simulation. Driver's behavior illustrates how vehicle drivers make their decisions about safety distance, lane choice, and other driving decisions[88].

Driving behavior parameters consist of default values that allow users to change their scope in line with the conditions of the site to be studied. Since the drivers' behavior differs greatly from geographical location to another, Therefore, the default values for driving behavior parameters seldom match the domestic traffic characteristics and conditions of traffic for a specific zone[89].

Thus the default parameter values should be calibrated as shown in the Table (4-10) to obtain a simulation that represents the real world as closely as possible.

Table (4-10) Driving Behavior Parameters Selected for the Calibration of the Simulation Model

Parameter	Definition*	Range	Default value	Calibrated value
Average standstill distance	The average desired distance between stopped cars	(1-3)m	2	1.60
Lock ahead distance	Max & Min forward distance that the vehicle driver can see within the same link.	(0 Min.-250Max) m	75-150	30-100
Lock back distance	Max & Min back distance that the vehicle driver can see in order that reacts to other vehicles behind-within the same link.	(0 Min.-150Max) m	30-100	15-60
Vehicles occupation of the wrong lane	Occupation of a lane not assigned for the movement of the vehicle by a driver, such as Occupy the left-turn, whereas destination through	-	5%	0-14%
Driving behavior on adjacent lanes distance	The minimum distance between adjacent vehicles when vehicles are approaching the stop line.	-	2	1.10
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 right movement left movement after the green light changing lanes (speed decreases 10%)	-	No selected	selected

* The definitions are taken from the VISSIM 10 User Manual.

Sayed and Essa has shown the possibility of transferring driving behavior parameters calibration from one region to another with the same characteristics (social, cultural background, and geographical position) [90].

4.7.2 Validation of Simulations and SSAM Model

Calibration of the VISSIM model affects the quality of the safety assessment and thus reflects the correlation between the conflicts observed in the field and the conflicts extracted by the simulation approach.[25]. The simulation approach was validated after calibration over two days during peak hours.

Table (4-11) shows all types of conflicts (crossing, lane-change, and rear end) as well as clarified two simulation scenarios, which are the default and after calibration conducting along with the observed conflicts for one out of two days at 40 St. Intersection.

Table (4-11) Summary Numbers for Both Observed and Simulated Conflicts Before and After the Calibration for the Simulation Model

Time	App.	Crossing Conflicts			Rear-end Conflicts			Lane-change Conflicts			Total Conflicts		
		Ob.	Si^a.	Si^b.	Ob.	Si^a.	Si^b.	Ob.	Si^a.	Si^b.	Ob.	Si^a.	Si^b.
7:30 - 8:30	NB	2	3	3	8	14	12	6	7	8	16	24	23
	EB	1	4	3	9	12	5	4	6	6	14	22	14
	SB	2	3	2	8	13	11	5	9	6	15	25	19
	WB	2	4	3	13	14	15	6	6	7	21	24	25
8:30 - 9:30	NB	1	3	2	8	13	11	4	8	7	13	24	20
	EB	1	3	1	7	10	10	3	5	4	11	18	15
	SB	2	2	3	8	11	8	4	6	5	14	19	16
	WB	2	3	3	9	14	12	4	4	6	15	21	21
12:30 - 1:30	NB	0	3	2	7	10	12	3	7	5	10	22	19
	EB	1	1	0	6	10	9	3	5	3	10	16	12
	SB	1	2	1	11	15	13	4	4	4	16	21	19
	WB	2	5	3	12	12	14	5	7	4	19	24	21
1:30 - 2:30	NB	2	3	5	11	10	10	7	5	8	20	18	23
	EB	0	2	2	6	11	12	5	5	2	11	18	16
	SB	2	1	3	8	14	11	3	7	5	13	22	19
	WB	2	3	0	7	17	16	4	5	5	13	25	21

Ob./ Observed conflicts.
Si^a./ Simulated conflicts extracted from VISSIM simulation models before calibrated.
Si^b./ Simulated conflicts extracted from calibrated VISSIM simulation models.

The results showed that calibration of the model reduced the Mean Absolute Prevent Error (MAPE) and improved the compatibility between both the observed and the simulated conflicts as shown in Figure (4-21).
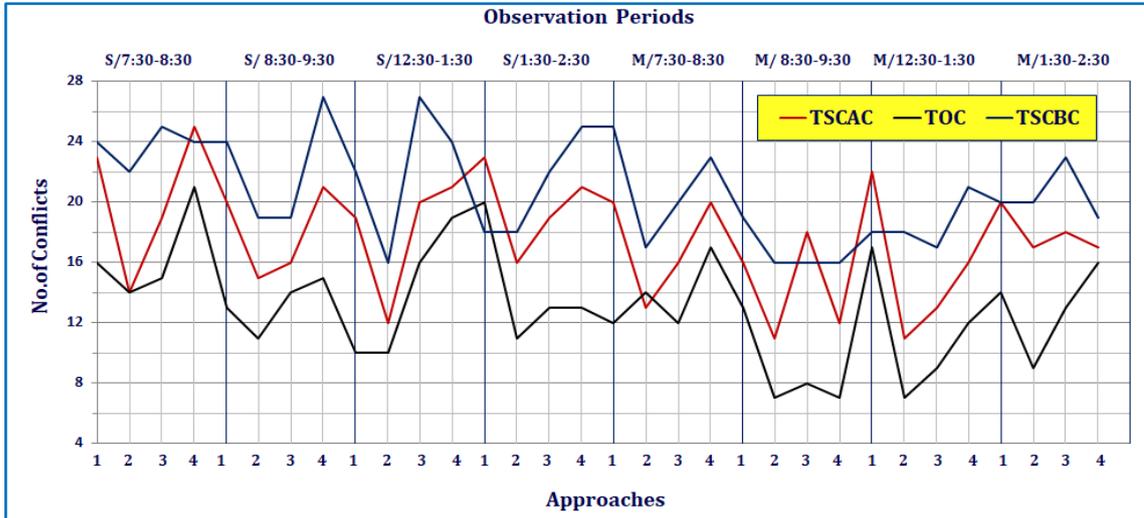
Figure (4-21) Relative Convergence between the Two Approaches After Calibrated.

TSCAC: Total simulated conflict after calibrated for approach.
TOC: Total observed conflict for approach.
TSCBC: Total simulated conflict before calibrated for approach.
(1,2,3,4):(North ,East ,West ,South) approach respectively.

The MAPE values are calculated based on equation (4.1)

$$\text{MAPE} = \frac{1}{n}\sum_{i=1}^{n} \left| \frac{c_s^i - c_f^i}{c_f^i} \right| \qquad [24] \qquad\qquad (4.1)$$

Where:

n= The observations number.

c_s^i=The simulated conflicts number at time interval i.

c_f^i=The field observed conflicts number at time interval i.

The MAPE reduced values were varied between the three types of conflicts and reached the highest percentage decrease in lane-change conflicts, reaching 33%. MAPE values after calibration for total conflicts reduced from 62% to 37%. In more detail, the MAPE values were reduced from 55% to 33% for the rear-end conflicts, from 67% to 47% for the crossing conflicts, and from 71.5% to 38.5% for the crossing conflicts.

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Pearson correlation coefficient (PCC) was used for validation of the conflicts extracted from SSAM by calculating the correlation between the field and simulated conflicts as shown in Table (4-12).

Table (4-12) Correlation between Simulation and Field Conflicts

N= 32		OB.C	SIM.C	OB.R	SIM.R	OB.L	SIM.L	OB,T	SIM.T
OB.C	Pearson Correlation	1	.688**	.494**	.186	.636**	.639**	.746**	.640**
	Sig. (2-tailed)		.000	.004	.309	.000	.000	.000	.000
SIM.C	Pearson Correlation	.688**	1	.604**	.077	.673**	.645**	.758**	.670**
	Sig. (2-tailed)	.000		.000	.676	.000	.000	.000	.000
OB.R	Pearson Correlation	.494**	.604**	1	.533**	.530**	.400*	.894**	.732**
	Sig. (2-tailed)	.004	.000		.002	.002	.023	.000	.000
SIM.R	Pearson Correlation	.186	.077	.533**	1	.300	.063	.466**	.695**
	Sig. (2-tailed)	.309	.676	.002		.096	.731	.007	.000
OB.L	Pearson Correlation	.636**	.673**	.530**	.300	1	.618**	.830**	.700**
	Sig. (2-tailed)	.000	.000	.002	.096		.000	.000	.000
SIM.L	Pearson Correlation	.639**	.645**	.400*	.063	.618**	1	.607**	.720**
	Sig. (2-tailed)	.000	.000	.023	.731	.000		.000	.000
OB.T	Pearson Correlation	.746**	.758**	.894**	.466**	.830**	.607**	1	.833**
	Sig. (2-tailed)	.000	.000	.000	.007	.000	.000		.000
SIM.T	Pearson Correlation	.640**	.670**	.732**	.695**	.700**	.720**	.833**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	
**. Correlation is significant at the 0.01 level . *. Correlation is significant at the 0.05 level									
OB: Observed , SIM: Simulated , C: Crossing , R: Rear-end , L: Lane-change and T: Total Conflicts									

This table shows the PCC between simulation and similar field conflicts at the 40 St. Intersection, where all relationships were direct. Ranged from moderate with the lowest correlation coefficient (0.533) for rear-end conflicts, strong for lane changes and crossing conflicts, with two correlation coefficient values (0.618 and 0.688) respectively.

Followed by total conflicts with the highest correlation (0.833) that classified strong correlation[91], all p-values (0.000 & 0.002) <0.01, which are statistically significant at a significance level 0.01. Figure (4-22) shows the linear relationship between the two approaches at the 40 St. Intersection. Correlation analysis of the other sites ranged (0.565-0.791) & (0.659-0.863) details in Appendix D.
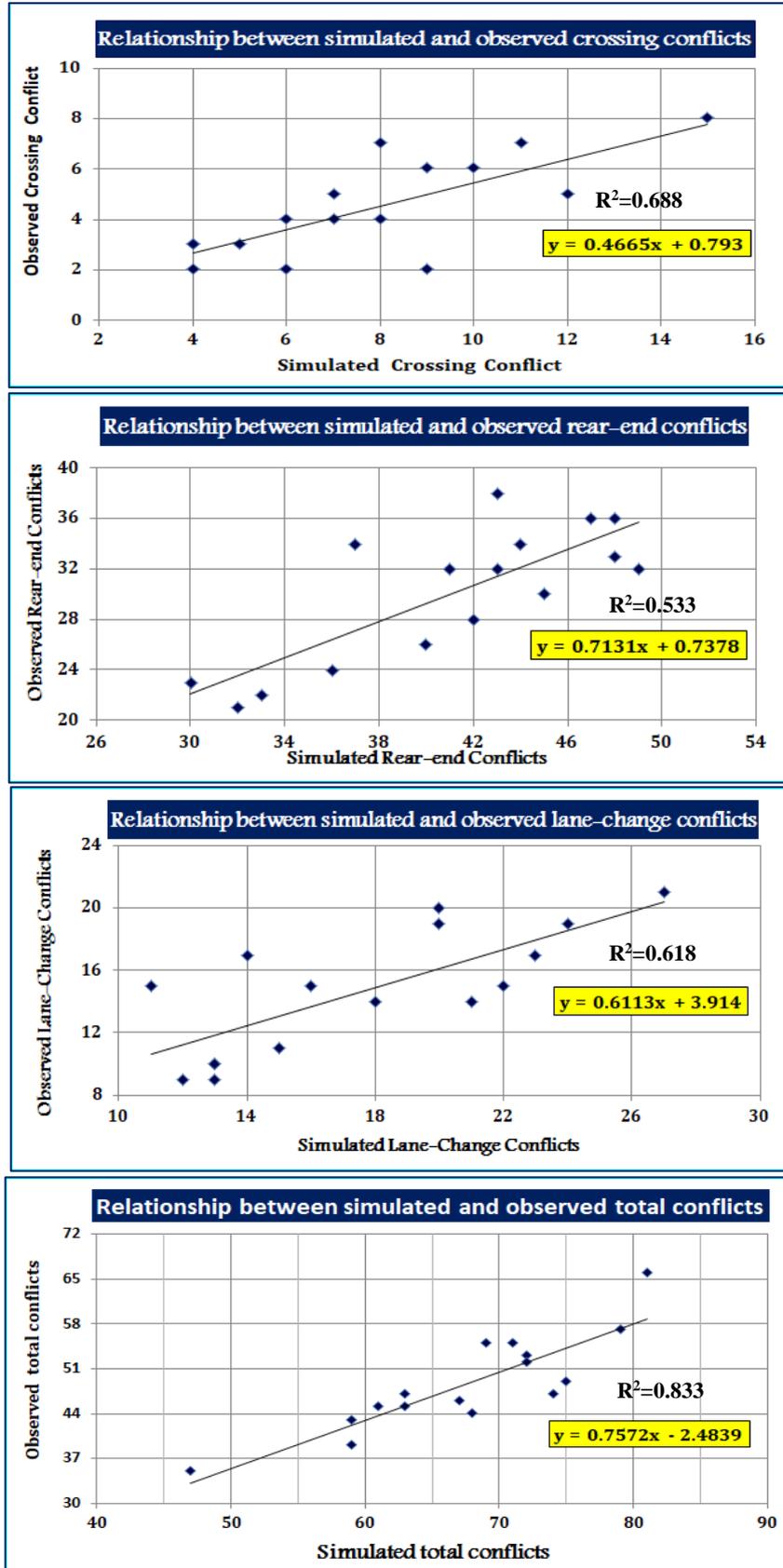
Figure(4-22) Relationship between Simulated and Observed Conflict

4.8 Relationship of conflicts with some traffic characteristics

Generally, Traffic flow characteristics like traffic volume, speed, and queue length directly affect the probability and crash severity. Yet, the influences of those characteristics respecting safety are not clear [92][93].

4.8.1 Traffic Conflicts with Traffic Volume

An acute understanding of this relationship is essential to develop traffic safety management and decrease crash occurrence. The relationship between conflict frequency and traffic volume fixates into one of two categories (linear and non-linear).

A software SPSS was used for developing a volume-conflict prediction model at 40 St. Intersection according to data collected from 50 simulations run on different traffic volumes in each run with the assumption that traffic characteristics will remain constant and not be affected by an increase or decrease in traffic volumes, as well as the geometric properties of the site remaining constant. Figure (4-23) explains the Linear and non-liner Relationship between hourly conflict frequency (HCF) and hourly traffic volume(HTV).
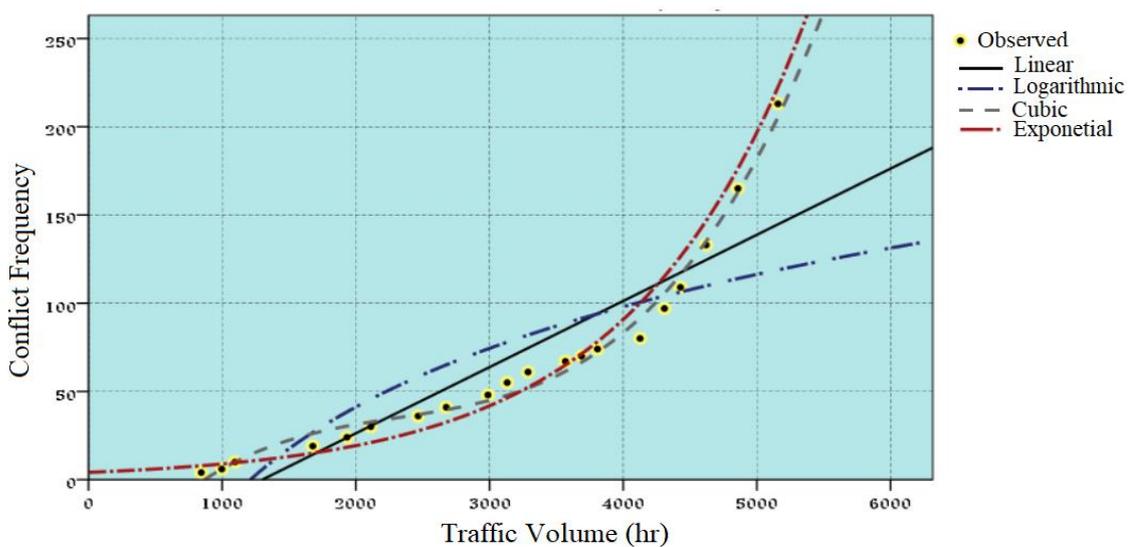
Figure (4-23) Linear and Non-Linear Relationship between HTV and HTC.

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The four models are presented as follows:

1-Linear equation: **Y = bo + (b1 *x).**

2-Logarithmic equation: **Y = bo + (b1 * ln(x)).**

3-Cubic equation: **Y = bo + (b1 * x) + (b2 * x**2) + (b3 * x**3).**

4-Exponential equation: **Y = bo * (e**(b1 * x)).**

Where:

Y= hourly conflict frequency.

x= hourly traffic volume.

bo,b1,b2,b3=parameter estimates.

Summary of models and parameter estimates statistics for variables used in conflict prediction for all models as shown in Table (4-13).

Table (4-13) Model Summary and Parameter Estimates

Dependent Variable: Conflict frequency

Equation	Model Summary			Parameter Estimates			
	R Square	F	Sig.	Constant	b1	b2	b3
Linear	.829	87.42	.00	-48.745-	.038		
Logarithmic	.666	35.87	.00	-582.63-	82.06		
Cubic	.989	467.58	.00	-66.478-	.108	-4.17E-5	5.99E-9
Exponential	.944	304.42	.00	4.101	.001		

 The independent variable is HTV.

The statistical analysis showed that the best prediction for the frequency of conflicts as a result of changing traffic volumes is represented by the equation of the cubic model, where the coefficient of determination (R^2) is 0.989 with a p-value 0.00 <0.01, which is statistically significant at a significant level 0.01 .Also, indicate a highly significant statistical correlation existing between HTV and HCF.

4.8.2 Traffic Conflicts with Queue Length

In signaled intersections, the length of the queue is important to determine the quality of traffic and reflects the intersection's performance[94]. Queue lengths (maximum and average) were calculated by queue counters in VISSIM at the stop lines on the links (approaches) of the intersections until the upstream position for 10 cycle lengths (can be calculated at any point and any time interval). Figure (4-24) displays the results of the queue lengths according to the VISSIM analysis at the 40 St. Intersection.
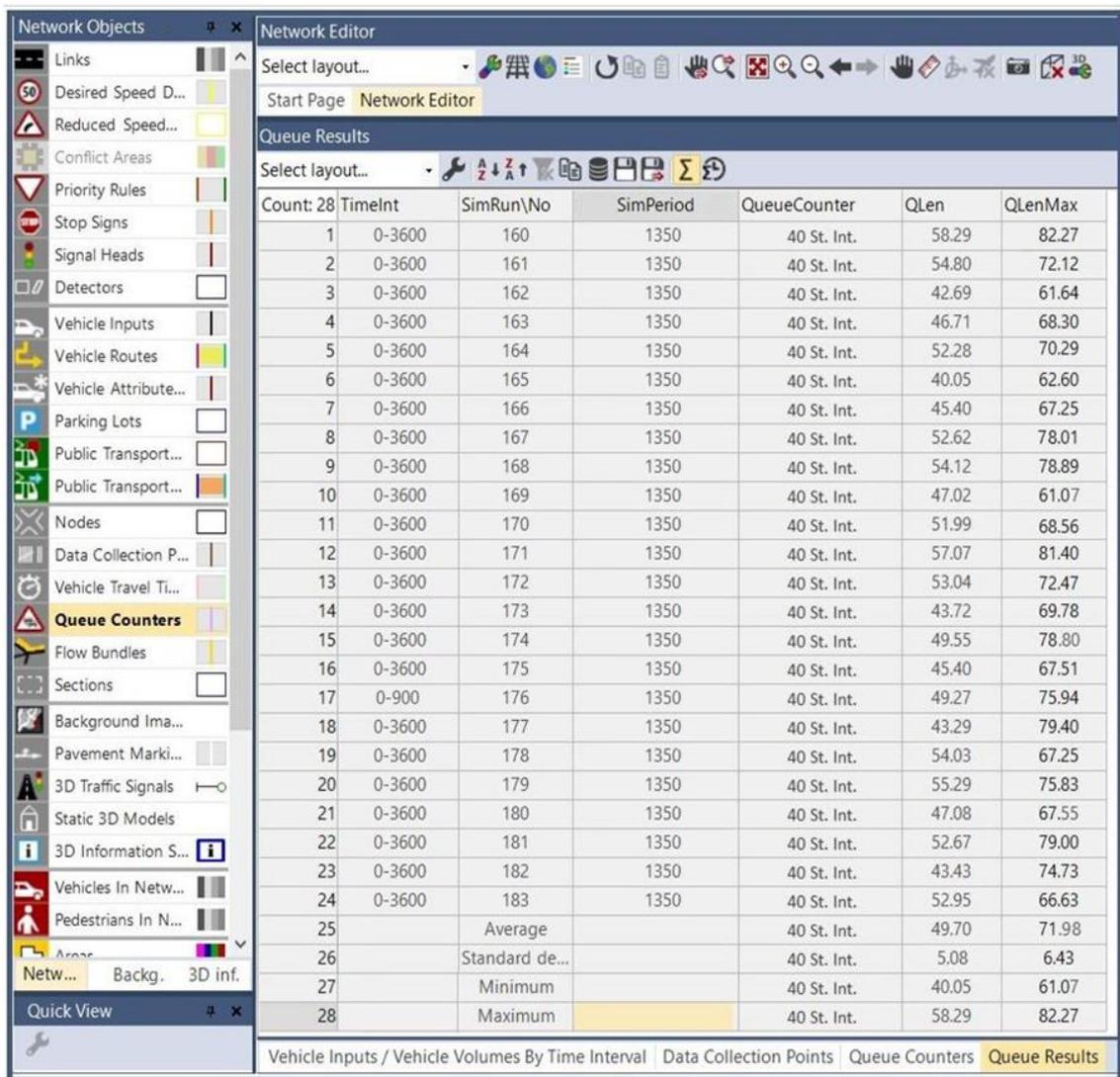
Figure (4-24) VISSIM Screenshot Showing Queue Lengths Counters

Queue lengths are recorded in each link and connecter, even the last vehicle entering the queue at every time step, in length units terms, not numbers of vehicles. Figure (4-25) displays the average and maximum queue lengths in each approach at peak and off-peak hours at the 40 St. Intersection.
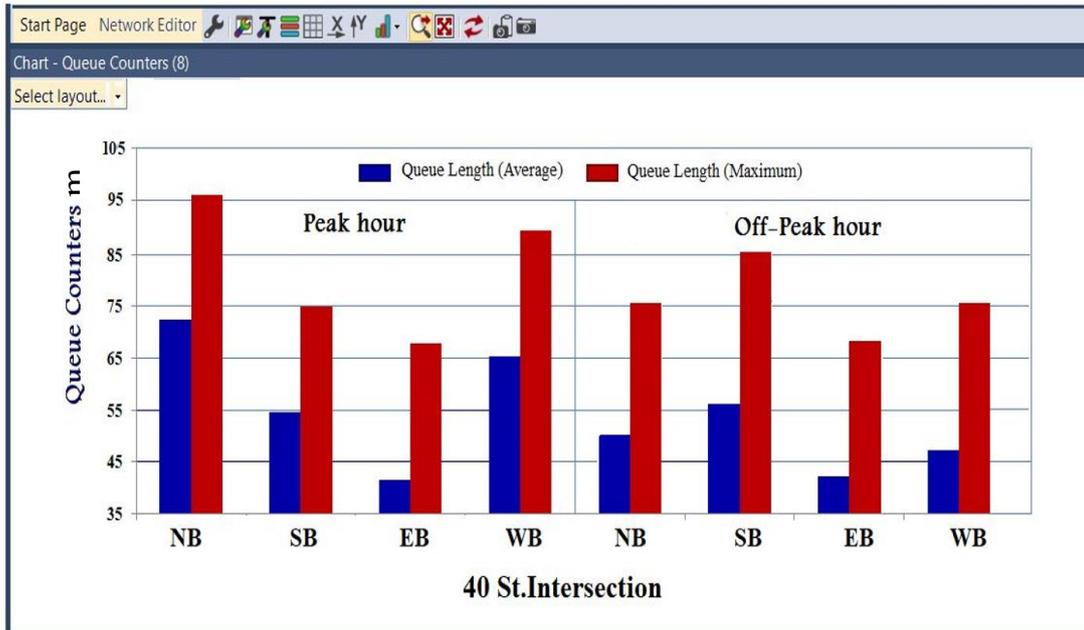
Figure (4-25) Queue Results Chart Extracted from Direct Output of Queue Evaluation at Links

The curve estimation was investigated in the SPSS statistic software to predict the (HTC) from (QL) for the three locations. Figure (4-14) shows a test between four models to choose the best one to anticipate conflicts from the QL at Bab Al-Hussein Intersection.

Table (4-14) Investigation of Models Summary and Parameter at Bab-AL-Hussein

Dependent Variable: Conflict

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.825	103.95	1	22	.000	31.683	.359		
Quadratic	.836	53.63	2	21	.000	20.479	.661	-.002-	
Cubic	.844	35.98	3	20	.000	56.162	.797-	.017	-7.69E-5
Exponential	.816	97.43	1	22	.000	36.591	.006		

The independent variable is Queue length.

The analysis showed different model forms, that the best fit model is the cubic model for the intersection of Bab Al-Hussein, while the simple linear

regression model the best fit for both intersections of Bab Al-Mashhad and 40 St. as shown in the table (4-15).

Table (4-15) Model Forms for Q_L-Based Conflict Prediction Models

Model No.	Queue length-based conflict prediction models	Best fit models based on R-square and significant of model and their parameter	
1	Predict HTC(40SI) based on Q_L(40SI)	$HTC = \beta0 + \beta1\ Q_L$	Linear
2	Predict HTC(BHI) based on Q_L(BHI)	$HTC = \beta0 + \beta1\ Q_{L+} \beta2\ Q_L{}^2 + \beta3\ Q_L{}^3$	Non – linear (Cubic)
3	Predict HTC(BMI) based on Q_L(BMI)	$HTC = \beta0 + \beta1\ Q_L$	Linear

40SI:40 Street Intersection   BHI: Bab-AL Hussein Intersection   BMI: Bab-AL Mashhad Intersection

The three models predicted conflicts (HTC) at sites are stated as follows:

Model No.1 $HTC = -45.98 + 2.17 * Q_L$

Model No.2 $HTC = 56.16 - 0.797 * Q_L + 0.017 * Q_L{}^2 - 7.69 * 10^{-5} * Q_L{}^3$

Model No.3 $HTC = 25.481 + 0.344 * Q_L$

HTC: Hourly traffic conflicts (c/h) Q_L.: Average queue length (m).

Table (4-16) displays the coefficient of determination and significance for all the three models' constants and variables.

Table (4-16) Coefficient of Determination and Significant for Models

Coefficients

Model No.		Unstandardized Coefficients		Standardized Coefficients			
		B	Std. Error	Beta	t	R Square	Sig.
1	QL(40 St.I)	2.170	.221	.902	9.823	0.814	.000**
	(Constant)	-45.980-	11.035		-4.167-		.000**
2	QL(BHI)	-.797-	1.519	-2.017-	-.524-	0.844	.000**
	QL(BHI) ** 2	.017	.019	6.863	.872		.000**
	QL(BHI) ** 3	-7.690E-5	.000	-4.012-	-.974-		.000**
	Constant)	56.162	37.963		1.479		.000**
3	QL(BMI)	.344	.033	.910	10.291	0.828	.000**
	(Constant)	25.431	2.162		11.761		.000**

** Correlation is significant at the 0.01 level

The coefficient of determination (R^2) is 0.814 with a p-value < 0.001 for model No.1, 0.844 with p-value < 0.001 for model No.2, and 0.828 with p-value < 0.001.Generally, indicated all the correlations between dependent and independent variables are significant with a p-value < 0.01, a good correlation was found between HTC and Q_L that indicating the predicted conflicts increasing with increase queue length at intersections.

Figure (4-26) displays the model for the 40 St. Intersection. Appendix D contains some details of the processes for analyzing and calculating these lengths, the conflicts frequency corresponding to those lengths, and a statistical description of the dependent and independent variables for all prediction models.
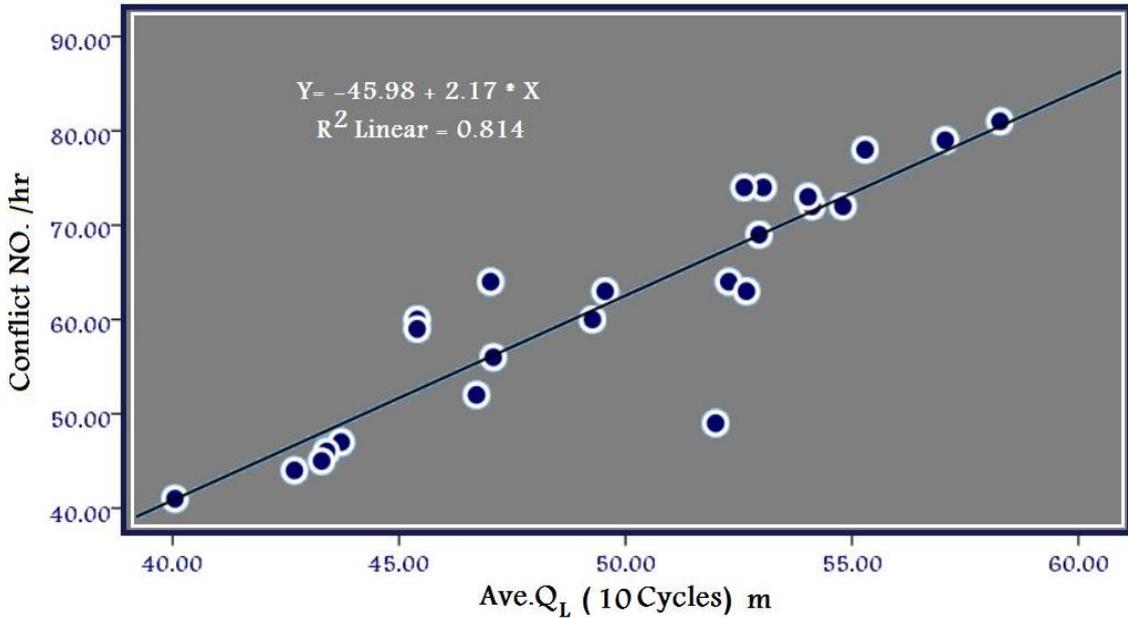
Figure (4-26) Linear Relationship between HTC and Q_L

The results showed that queue length has a double effect on safety; it increases the frequency of conflicts at the same time reducing the severity of conflicts; this is an expected result due to the impact of the queue length on reducing speeds, although, the speeds are often nearby to each other at signalized intersections and the facility is congested, so rear-end conflicts increase and there be an increase in lane-change conflicts by a lower percentage. Predictive models showed that increasing the queue length by 10% increases the frequency of conflicts by 20%.

4.9 Proposed Countermeasures for Intersections

The simulation approach has an ideal advantage over other methods, which is to examine and evaluate the effectiveness of the countermeasures before they are introduced for implementation (conflict-based simulation method is proactive in itself).

4.9.1 Countermeasures at 40 St. Intersection

Northern and Southern Approaches

- Expanding the intersection entry area at the expense of the leaving area of the intersection by:-

A- Shifting the tapered middle island that has narrow width before the stop line, 3 m towards the left.

B- Cut a part of the medium island 2.7 meters wide along a length that starts 30 meters below the stop line and continues until the end of the queue at peak hours.

- Increasing the area of intersection to avoid the lack of straightness that occurred as a result of the procedure taken in A.

Eastern Approach

- Addition of a right lane whose width is provided by from the right sidewalk, this lane designating to serving the movement towards the right The old right lane is used to move forward (Jabil region) and cut 2 .4 meters from the triangular island that separates the right-wing movement.

4.9.2 Countermeasures at Bab-AL Hussein Intersection

- It is necessary to increase the width of the northern approach by shifting the island, a distance of not less than 3 m towards the left, this does not affect the planning of the intersection because.

A- The intersection is three-legged (no southern approach) thus intersection surpasses the lack of straightness of the movement.

B- The presence of wide lanes (lanes carrying vehicles that leave the intersection towards 40 Street), which can bear the creeping of the middle island towards them.

- Increasing the width of the area entering the intersection of the eastern approach, starting from the stopping line and reaching the (Muqam Rad Al Shams) by reducing the width 3 m of the intermediate island in favor of the width of the lanes.

4.9.3 Countermeasures Results Summary

The simulation outputs showed that the countermeasures was reduced the total conflicts at the 40 St. intersection with a percentage of 18%, distributed (18%crossing,21% rear-end, and 15% lane change), while at Bab Al-Hussein intersection with a percentage of 21%, distributed (14% crossing,21% rear-end, and 23% lane change), (These ratios represent the average of 10 simulated runs for each site).

This reduction in the number of conflicts due to one countermeasure is (increasing the lane width for some intersection approaches) is enough to convert the evaluation of both intersections (40 St. and Bab Al Hussein) from high-risk to evaluating them as moderate-risk intersections.

Safety can also be improved by the following:

- Optimization geometric design, cycle length, and providing protected left-turn lane reducing total crashes by percent 10 % at signalized intersections according to HSM.
- Replacing U-turn movement inside the intersection with U-turn before entering the intersection area.

These countermeasures were limited to increasing the width of the lanes only. Therefore, it's important to conduct a study that includes all potential countermeasures because the countermeasures are complex and intertwined.

CHAPTER FIVE

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The most important conclusions that derive from the analysis of the results and fieldwork data can be summarized in the following points:

1- The optimal thresholds for the primary safety indicators (TTC & PET) at the intersections, varying TTC (1.5-1.8 s) and PET (4.7-5.3 s), and it is wrong to use TTC value =1.5 s. PET = 5 s or that extrapolated from previous sites and studies.

2- VISSIM calibration reduced the MAPE and improved the compatibility between observed and simulated conflicts. MAPE for overall conflicts decreased from (62% to 37%).

3- PCC between simulation and similar field conflicts ranged from moderate with PCC (0.533) for RE conflicts, Strong for LC and C conflicts with two correlation coefficient values (0.618 and 0688), respectively.

4- Rear-end conflicts prevailed at all intersections until they reached 60% of the total conflicts at the Bab- Al- Hussein intersection and (53%) at each Bab-AL Mashhad and 40 St. Intersection.

5- The severity of conflicts for all intersection approaches ranged from TTC=0.74s at Bab-AL Hussein intersection, indicates high risk, even up TTC=1.8s at the WB approach of Bab-AL Mashhad intersection, refers to low risk in that approach.

6- 40 St and Bab Al-Hussein intersections were classified as high-risk intersections TTC (0.86 & 0.82)s respectively, while the Bab Al-Mashhad intersection was classified as a medium-risk intersection.

7- The simulation of hypothetical scenarios showed, countermeasure reduced the total conflicts at the 40 St. intersection with a

percentage 18%, distributed (18%C,21% RE, and 15% LC) and Bab Al-Hussein intersection with a percentage 21%, distributed (14% C,21% RE, and 23% LC), This decreasing in the conflicts number due to one countermeasure (increasing the lane width of some intersection approaches) is enough to convert the evaluation of both intersections from high-risk to evaluating them as moderate-risk.

8- Queue length has a double effect on safety increases the conflicts frequency at the same time reducing the conflicts severity, so conflicts increase with increased queue length where predictive models showed that an increase in queue length by 10% leads to an increase in the conflicts frequency by 20%.

5.2 Recommendations

Everything recoups except the loss of human life. It is expected to reduce these losses through the following recommendations:

1- Establish a road network that meets the requirements of road users, regularly scheduled maintenance of existing road network and infrastructure. To make the roads safer.

2- Providing pavements with a high skid resistance can contribute positively to achieving safety. Avoid the use of narrow lanes and eliminate parking cars at the intersection. Improving water drainage and geometry layout.

3- Provide clear sight at intersections and improve visibility of signals using mast arms to enhance the pre-warning and remove visual noise (e.g., Advertising signs) that contribute to crashes.

4- Take advantage of geographic information systems (GIS) in recording traffic crashes with x, y coordinates by the traffic policeman even if the conflicting parties agree amicably.

5- Encouraging researchers to conduct further studies to improve safety in all traffic facilities to enable drivers to avoid crashes and lead an educational campaign highlighting that signalized intersections as "the most dangerous sites on the roads" be considered.

6- Consolidate traffic awareness towards familiarity with traffic rules and laws and Strict emphasis on adherence to it.

7- Sites studied, specially Bab-AL Hussein, may be nominees for transformation to interchanges as a potential countermeasure to reduce crashes.

8- Opening an administrative unit in the Traffic Directorate concerned traffic crashes and safety in coordination with other governmental and non-governmental institutions concerned with safety.

9- Finally, there is an urgent need to include VISSIM in the academic study of one of these degrees (Bachelor, Higher Diploma, and Masters).Four hundred universities, 2500 urban cities, 120 countries use simulation software for developing and solving transportation matters. Without exaggeration, there is no transportation engineering without simulation software,(results of the operational characteristics of the traffic network are displayed every second).

5.3 Future Work

1- After determining the lack of safety at sites, it's necessary to conduct a study that includes all potential countermeasures to improve safety at signalized intersections by utilizing the powerful feature of simulation as a proactive examination for countermeasures.

2- To expand the scope of the study, it is proposed to conduct an analysis by VISSIM and SSAM models of other traffic facilities, particularly the merging areas in the interchanges and U-turns in arterial roads, especially U-turn, due to many crashes occur there (e.g, the U-turn near Al-Karama street) the problem is double due to merging and U-turn at the same time).

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APPENDICES

Appendix (A)
Tables, Figures and Data Related to Traffic Safety in Iraq

The Number Accidents Recorded According Accident Nature in Iraq Governorates Year 2019

Crash	Overturn	Run over	Others
56	20	129	0
290	38	33	16
246	8	283	0
658	166	302	0
605	43	500	0
517	98	235	52
219	43	108	0

Crash	Overturn	Run over	Others
124	27	90	3
93	20	67	0
395	90	234	234
532	54	607	0
501	142	246	0
165	38	130	13
429	127	265	0
836	85	540	0

Productions GIS Center/Central Statistical Organization   Source ;Transport Statistics Directorate Of Communications

Note: This map is not consider as an official document for administrative boundaries but for census only

Figure (A-1) Type of Crashes According Crash Nature in Iraq for the Year 2019

A-1

Table(A-1) The Main Reasons for the Recorded Traffic (Deaths) According to the Governorates for the Year 2019

Governorate	Causes of Crashes										Total
	High Speed	Driving reverse direction	The wrong pass	Out allowed roundness	Non compliance with traffic priorities	Non comliance with the traffic signal	Driving under alcohol	Driving without license	Lack of attention	other	
Nineveh	58	9	8	1	8	5	0	0	3	0	92
Salah-ALdeen	41	0	3	0	3	0	1	9	11	0	68
Kirkuk	99	0	0	0	0	0	0	0	3	1	103
Dyala	171	17	32	5	3	5	8	1	20	0	262
Al - Anbar	34	4	9	1	0	0	0	0	11	0	59
Baghdad	108	22	42	15	17	9	0	8	37	0	258
Babylon	220	17	12	2	0	2	0	0	25	10	288
Karbela	70	2	13	2	6	2	4	8	14	4	125
Al-Najaf	178	2	0	0	0	0	0	0	7	0	187
Al-Qadysia	155	0	5	0	0	0	0	0	6	1	167
Al-Muthanna	72	6	11	6	3	0	1	0	5	12	116
Thi-Qar	259	0	0	0	0	0	0	0	0	0	259
Wasit	81	10	27	5	16	1	17	22	31	7	217
Missan	110	6	4	0	0	0	1	0	1	9	131
Basrah	212	10	17	13	4	15	4	0	29	0	304
Total	1868	105	183	50	60	39	36	48	203	44	2636

Source: Ministry of Interior /Agency of Police Affairs / Criminal Statistics Department.
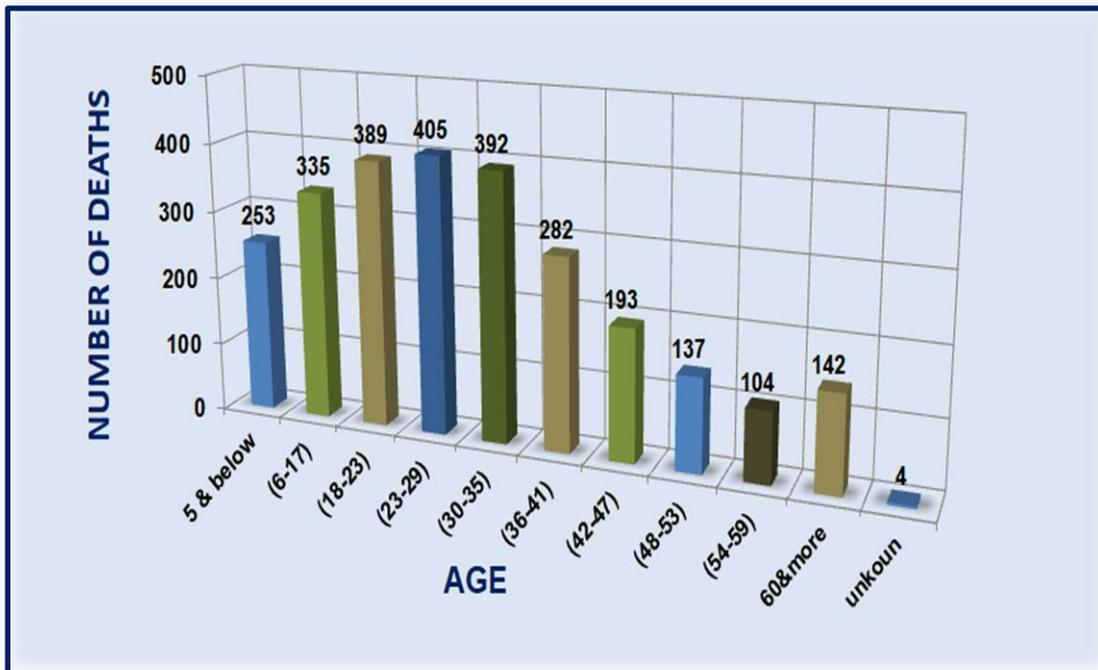
Figure (A-2) Number of Deaths Due to Traffic Crashes Recorded by Age Groups for the Years 2019.
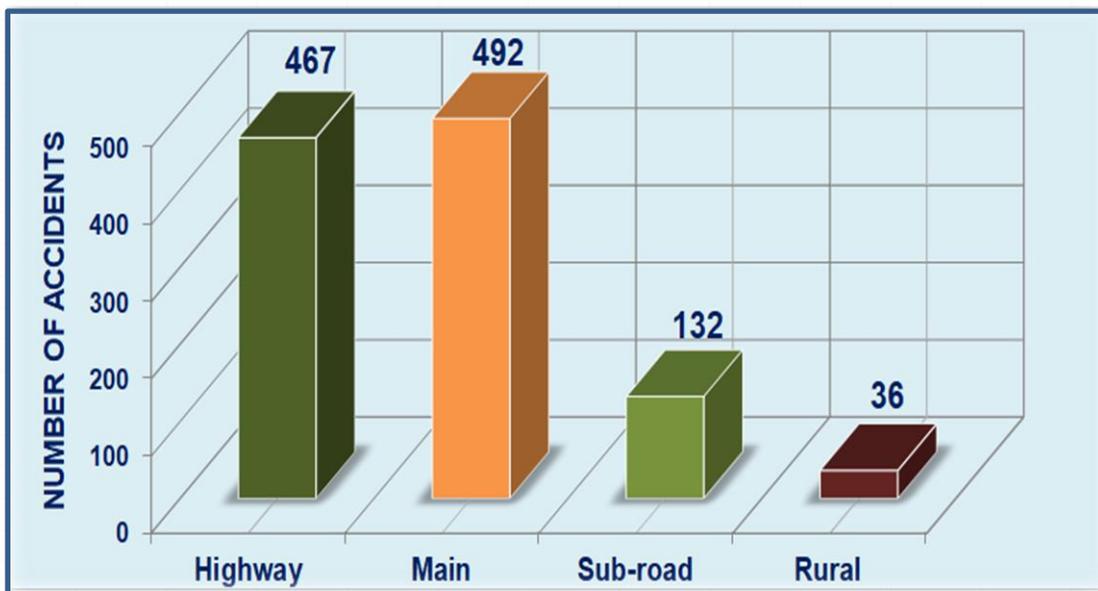
Figure (A-3)Traffic Crashes Proportion According Road Type for Babil Governorate in Year 2019

Appendix (B)
Tables Related to Chapter Two and Data Collect
Table (B-1) Summary of Classification of Safety Indicators According to (Time, Distance, Deceleration, and Others)

Type	Indicators name
Temporal Proximity Based	Time-to-Collision (TTC) or Time-Measured-to-Collision (TMTC) ; Time Advantage (Tadv) ; Time-to-Accident (TA) ; Gap time ; Post-Encroachment Time (PET) ; Headway (THW/H) ; Initial Attepted Post Encroachment Time (IAPET) ; Enchroachment Time [; Time to Intersection/Stop Line (TTI) ; Inverse of time-to collision (iTTC) [44]; The Second Order Predicted TTC (TTC 2nd); Time Exposed Time-to-Collision (TET) ; Time Integrated Time-to-Collision (TIT); Time to Line Crossing ; Modified Time-to-Collision (MTTC); Crash index (CI) ; Critical Gap .
Distance-Based	Proportion of Stopping Distance (PSD) ; Potential Index for Collision with Urgent Deceleration (PICUD) ; Unsafe Density (UD) ; Predicted minimum distance (PMD) ; Difference of Space Distance and Stopping Distance (DSS) ; Margin to Collision(MTC) ; Time Integrated DSS (TIDSS) .
Deceleration Based	Deceleration Rate to Avoid the Crash (DRAC); Dispersion of Acceleration during Unit Time in Unit Road Section ; Deceleration of Safety Time (DST) ; Criticality Index Function (CIF) ; Crash Potential Index (CPI); Overt Deceleration for Collision Avoiding (ODCA) ; Potential Deceleration for Collision Avoiding (PDCA) .
Others	Shock-Wave Frequency (SWF) ; Composite g-force and speed (Jerks); Standard Deviation of Lateral Position (SDLP) ; An accumulative safety indicators (J-value) ; Potential Energy (PE);Judgement Line of Brake Initiation (KdB) .

Table (B-2) Surrogate Indicators Potential for Developing Traffic Safety

Indicators	Computational equation	Suitable for crash type
Temporal Proximity		Rear-end, head-on, turning/weaving, hit objects/parked vehicle,crossing, hit pedestrian.
Time-to-Collision-TTC	$TTC_i(t) = \dfrac{X_{i-1}(t) - X_i(t) - l_i}{V_i(t) - V_{i-1}(t)}$	
Time-to-Accident (TA)	$TA = \dfrac{\Delta d}{v_i}$	Same as TTC
Headway (H)	$H = t_i - t_{i-1}$	Rear-end mainly,other such as turning, hit objects/parked vehicle
Post-Encroachment Time (PET)	$PET = t_2 - t_1$	Mainly for right angle or crossing crash ,hit rear- end, head on also
Time Exposed Time-to Collision (TET)	$TET_i^* = \sum\limits_{t=0}^{\Sigma_i} ((t) \cdot \tau_{sc})$	Same as TTC
Time Integrated Time -to Collision (TIT)	$TIT_i^* = \sum[TTC^* - TTC_i(t)] \cdot \tau_{sc}$	Same as TTC
Modified Time-to-Collision (MTTC)	$MTTC = \dfrac{-\Delta V \pm \sqrt{V^2 + 2\Delta aD}}{\Delta a}$	Vehicle-vehicle crash
Non-temporal Proximity indicators		
Potential Index for Collision with Urgent Deceleration(PICUD)	$PICUD\,(m) = \dfrac{V^2 - V_2^2}{2\alpha} + S_o$ $-V_2\Delta t$	Same as TTC
Proportion of Stopping Distance (PSD)	$PSD = \dfrac{RD}{MSD}$	Hit object (on road or road side), overturning
Difference of Space Distance and Stopping Distance (DSS)	$DSS = \left(\dfrac{-v^2}{2\bar{\mu}g} + d_2\right)$ $-\left(v_2\Delta t + \dfrac{-v_1^2}{2\mu q}\right)$	Rear-end, hit object, turning
Deceleration Rate to Avoid the Crash (DRAC).	DRAC $EXP\left(V_{FV,t}^t - V_{SV,t}\right)^2$ $= \left(X_{sv,t} - X_{rv,t}\right) - L_{sv,t}$	Rear-end ,Hit object /parked vehicle, Hit pedestrian, Merging and diverging maneuvers

Table (B-3) Traffic Volume Data and Vehicle Compositions at Approach (40 Street- AL-Zraaha) of 40 St. Intersection

TIME	Approach	Traffic Volume (veh./15 min)							
		Days of Observation							
		Sunday / 8-11-2020				Monday / 9-11-2020			
		Left	Through	Right	U-Turn	Left	Through	Right	U-Turn
7:30-7:45		70	95	41	10	59	80	40	14
7:45-8:00		71	102	45	14	58	91	42	16
8:00-8:15		62	165	35	19	47	170	31	22
8:15-8:30		72	162	40	17	72	159	43	21
TOTAL		**275**	**524**	**161**	**60**	**236**	**500**	**156**	**73**
8:30-8:45		57	128	35	15	48	109	34	18
8:45-9:00		43	110	33	19	48	97	33	17
9:00-9:15	40 Street- AL-Zraaha	64	99	42	15	48	103	42	15
9:15-9:30		71	102	32	23	69	93	31	19
TOTAL		**235**	**439**	**142**	**72**	**213**	**402**	**140**	**69**
12:30-12:45		64	75	35	13	57	66	35	12
12:45-1:00		61	144	40	21	56	129	42	14
1:00-1:15		66	122	34	17	58	113	31	19
1:15-1:30		71	79	38	16	69	80	40	19
TOTAL		**262**	**420**	**147**	**67**	**240**	**388**	**148**	**64**
1:30-1:45		60	117	31	16	61	100	36	16
1:45-2:00		57	164	30	12	46	152	27	15
2:00-2:15		70	187	32	14	56	169	20	17
2:15-2:30		70	156	35	20	56	168	31	13
TOTAL		**255**	**624**	**128**	**64**	**219**	**589**	**114**	**61**

Vehicle Compositions	Number of Vehicles				Proportion
	Left	Through	Right	U-Turn	
Car	236	463	132	54	86.76%
HGV	29	33	7	---	6.76%
Bus	10	28	22	6	6.48%

Table (B-4) Traffic Volume Data and Vehicle Compositions at Approach (AL-Jameaha-AL-Jabal) of 40 St. Intersection

TIME	Approach	Traffic Volume (veh./15 min)							
		Days of Observation							
		Sunday / 8-11-2020				Monday / 9-11-2020			
		Left	Through	Right	U-Turn	Left	Through	Right	U-Turn
7:30-7:45		119	89	55	5	94	85	44	9
7:45-8:00		99	70	50	8	87	70	43	7
8:00-8:15		76	85	52	7	72	78	47	8
8:15-8:30		103	77	51	9	91	76	52	6
TOTAL		**397**	**321**	**208**	**29**	**344**	**309**	**186**	**30**
8:30-8:45		84	90	54	8	86	86	47	7
8:45-9:00	AL-Jameaha-AL- Jabal	95	65	49	10	94	64	43	9
9:00-9:15		106	76	47	8	100	77	41	9
9:15-9:30		93	87	52	9	81	84	50	8
TOTAL		**378**	**318**	**202**	**35**	**361**	**311**	**181**	**33**
12:30-12:45		106	86	50	8	93	81	43	7
12:45-1:00		78	64	53	5	72	67	44	5
1:00-1:15		96	79	51	6	77	73	50	8
1:15-1:30		72	75	41	7	61	73	46	9
TOTAL		**352**	**304**	**195**	**26**	**303**	**294**	**183**	**29**
1:30-1:45		95	92	52	7	82	87	50	9
1:45-2:00		89	68	47	7	88	66	43	9
2:00-2:15		97	71	45	5	81	68	49	8
2:15-2:30		98	88	48	8	84	87	48	8
TOTAL		**397**	**319**	**192**	**27**	**335**	**308**	**190**	**34**

Vehicle Compositions	Number of Vehicles				Proportion
	Left	Through	Right	U-Turn	
Car	365	270	177	29	88.06%
HGV	12	30	19	---	6.38%
Bus	20	21	12	---	5.55%

Table (B-5) Traffic Volume Data and Vehicle Compositions at Approach (AL-Jabal - AL-Jameaha) of 40 St. Intersection

TIME	Approach	Traffic Volume (veh./15 min)							
		Days of Observation							
		Sunday / 8-11-2020				Monday / 9-11-2020			
		Left	Through	Right	U-Turn	Left	Through	Right	U-Turn
7:30-7:45		90	126	63	18	77	114	56	20
7:45-8:00		88	120	59	25	89	107	52	19
8:00-8:15		75	83	48	22	66	75	41	16
8:15-8:30		88	100	55	23	83	93	50	22
TOTAL		**341**	**429**	**225**	**88**	**315**	**389**	**199**	**77**
8:30-8:45		92	129	50	27	77	106	41	23
8:45-9:00	AL- Jabal - AL-Jameaha	71	90	43	17	68	97	38	20
9:00-9:15		65	79	40	23	71	69	42	18
9:15-9:30		79	122	38	26	72	119	31	22
TOTAL		**307**	**420**	**171**	**93**	**288**	**391**	**152**	**83**
12:30-12:45		100	106	59	16	88	92	46	15
12:45-1:00		96	106	55	22	83	95	52	27
1:00-1:15		77	74	47	18	63	75	43	17
1:15-1:30		86	97	51	23	69	90	47	22
TOTAL		**359**	**383**	**212**	**79**	**303**	**352**	**188**	**81**
1:30-1:45		82	109	52	23	73	90	49	23
1:45-2:00		73	109	48	30	73	87	49	20
2:00-2:15		59	73	43	22	60	65	34	17
2:15-2:30		68	101	40	25	71	89	31	29
TOTAL		**282**	**392**	**183**	**100**	**277**	**331**	**163**	**89**

Vehicle Compositions	Number of Vehicles				Proportion
	Left	Through	Right	U-Turn	
Car	315	358	221	81	90%
HGV	26	11	22	7	6.0%
Bus	---	30	12	---	4.0%

Sample of Spot Speed Data

Table (B-6) Speed Data 40 Intersection: Approach AL-Zaraha-40 Street

Vehicle No.	Time (sec)	Spot Speed (kph)	Vehicle No.	Time (sec)	Spot Speed (kph)	Vehicle No.	Time (sec)	Spot Speed (kph)
1	5.5	22.13	34	5.4	22.50	67	4.2	23.1
2	5.3	22.88	35	4.6	26.38	68	4.6	21.1
3	6.1	19.88	36	5.7	21.38	69	6.1	16.2
4	6.0	20.25	37	6.1	19.88	70	6.0	16.2
5	5.1	23.75	38	6.2	19.63	71	5,3	18.3
6	5.0	24.25	39	6.3	19.25	72	5.8	16.8
7	4.9	24.75	40	5.9	20.63	73	5.7	17.1
8	4.9	24.75	41	5.9	20.63	74	5.3	18.3
9	5.4	22.50	42	4.6	26.38	75	5.7	17.1
10	5.8	21.00	43	5.8	21.00	76	5.7	17.1
11	6.0	20.25	44	5.2	23.38	77	6.2	15.7
12	6.3	19.25	45	5.3	22.88	78	4.4	22 .1
13	6.1	19.88	46	5.0	24.25	79	4.7	20.7
14	6.6	18.38	47	5.7	21.38	80	5.7	17.1
15	4.8	25.38	48	6.0	20.25	81	6.6	14.7
16	4.7	25.88	49	6.3	19.25	82	5.9	16.5
17	4.2	28.25	50	5.6	21.75	83	6.4	15.2
18	5.3	22.88	51	5.3	22.88	84	6.0	16.2
19	5.7	21.38	52	4.9	24.75	85	4.9	19.8
20	5.6	21.75	53	5.5	22.13	86	5.7	17.1
21	5.7	21.38	54	6.6	18.38	87	5.8	16.8
22	5.4	22.50	55	5.1	23.88	88	6.1	15.9
23	4.8	25.38	56	4.4	27.63	89	5.3	18.3
24	4.6	26.38	57	4.9	24.75	90	6.4	15.2
25	5.0	24.25	58	5.4	22.50	91	5.4	18.0
26	6.2	19.63	59	5.9	20.63	92	4.9	19.8
27	5.4	22.50	60	5.8	21.00	93	4.6	21.1
28	6.0	20.25	61	5.3	22.88	94	5.3	18.3
29	5.6	21.75	62	5.7	21.38	95	5.5	17.7
30	6.6	18.38	63	5.5	22.13	96	5.0	19.4
31	5.3	22.88	64	6.2	19.63	97	5.8	16.8
32	6.1	19.88	65	5.6	21.75	98	5.6	17.4
33	5.5	22.13	66	6.1	19.88	99	6.2	15.7

Appendix (c)

Figures, Related to Modeling Intersections in VISSIM
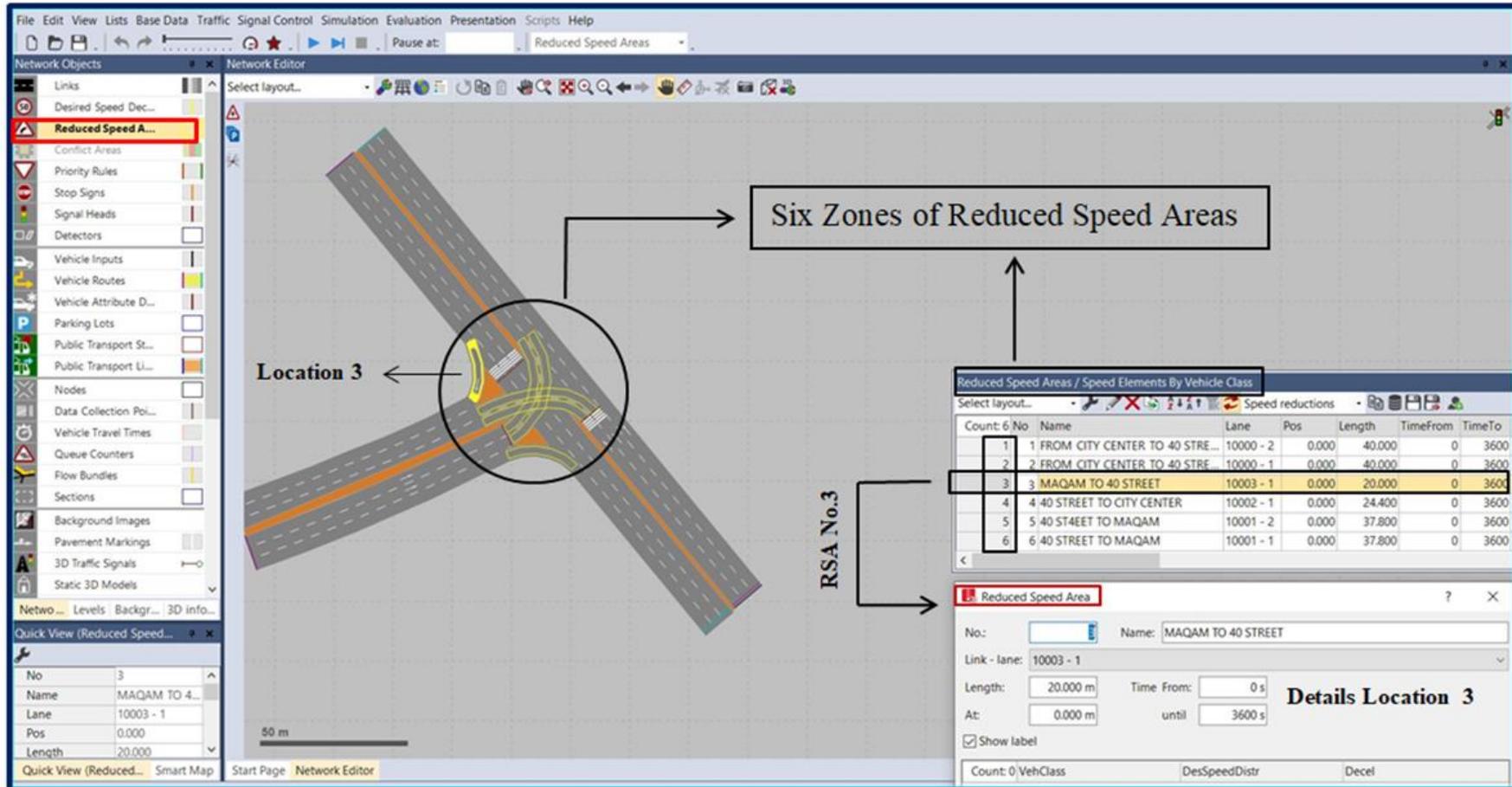
Figure (C-1) Locations of Reduced Speed Areas for the Bab Al Hussein Intersection Site

C-1
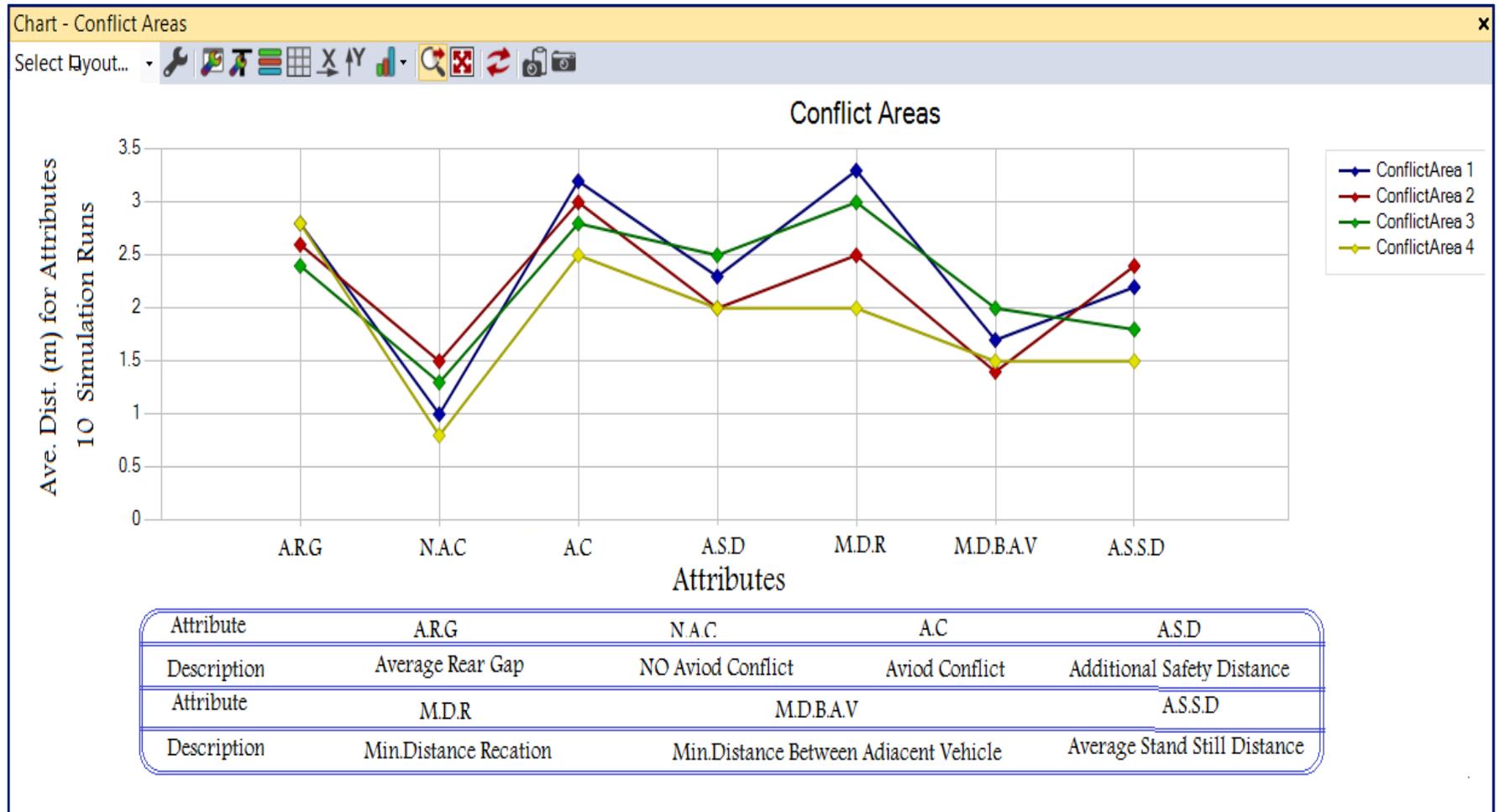
Figure(C-2) Some Features of Some Conflict Areas at the 40 St. Intersection
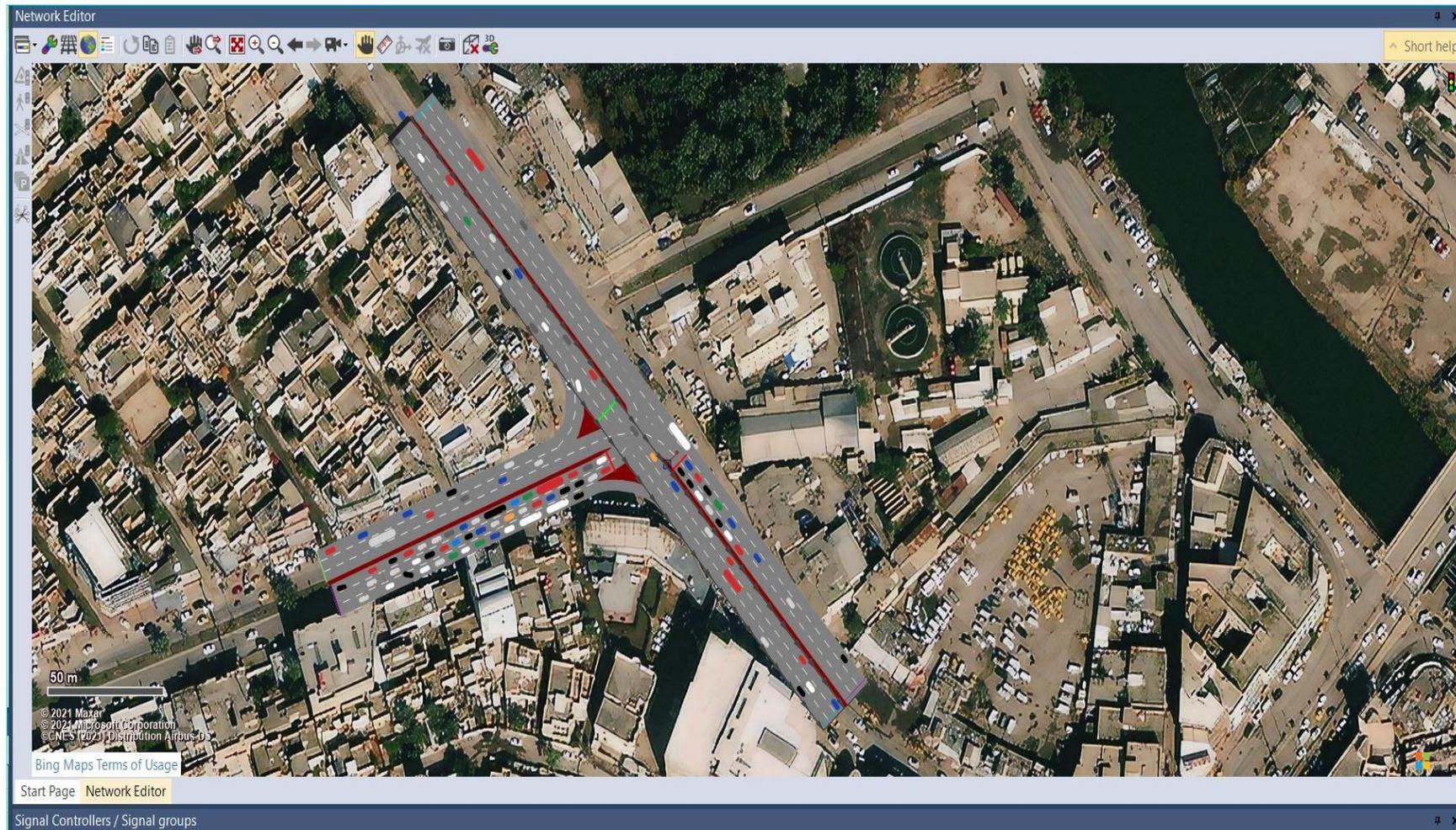
Figure (C-3) A 2D Simulation of the Right Lane for Bab Al-Hussein Intersection, Showing that it is Not Subordinate to the Light Signal
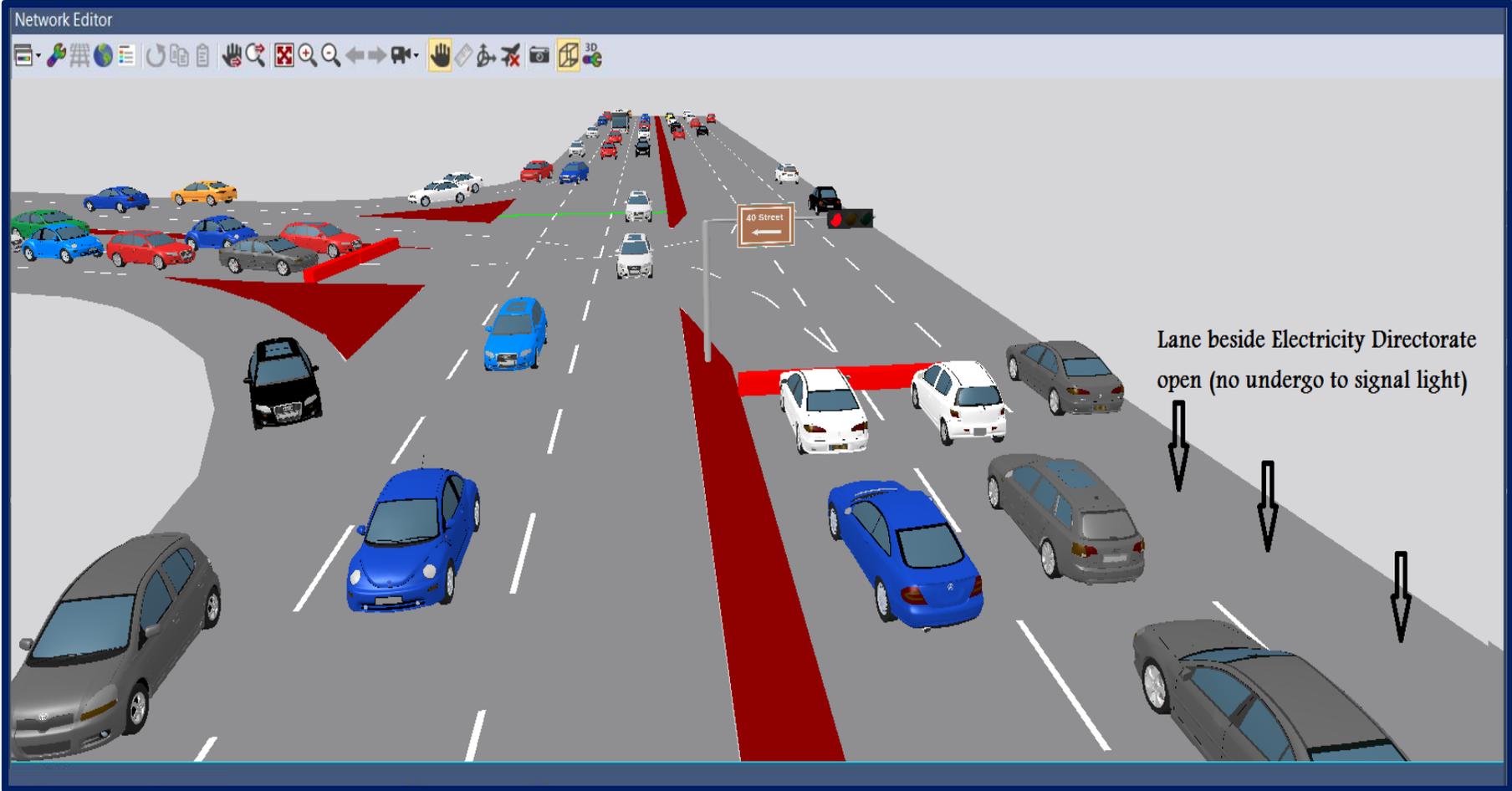
Figure (C-4) A 3D Simulation of the Right Lane for Bab Al-Hussein Intersection, Showing that it is Not Subordinate to the Light Signal (Open)
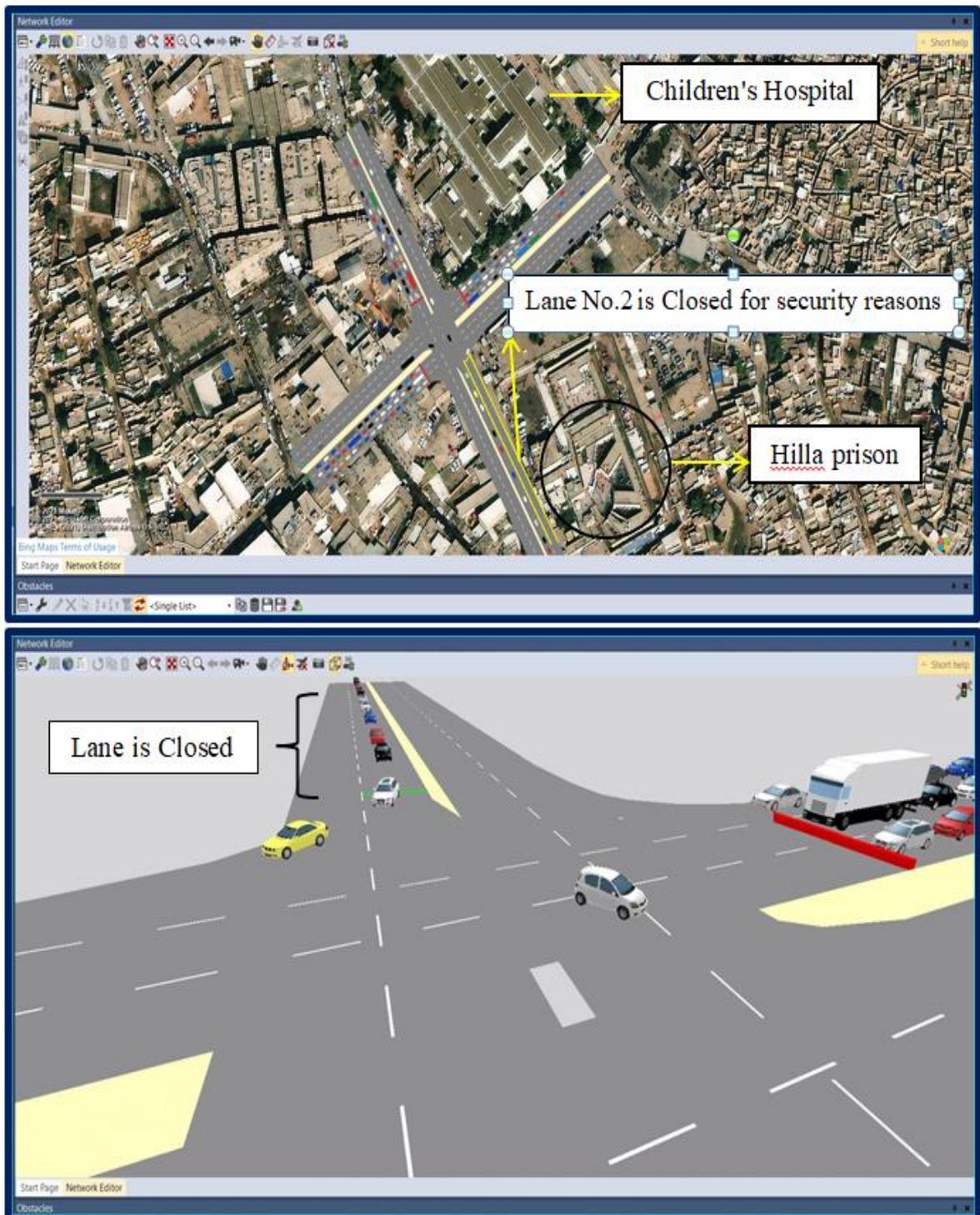
Figure (C-5) A 2D And 3D Simulation of a Prison Street for Bab AL-Mashhad Intersection Showing the Second Lane Is Closed

Appendix (D)
SSAM's Analysis of Trajectory Files
Table (D-1) SSAM Outputs of Surrogate Safety Measures of Conflicts at (40 St.) Intersection

Trj File	TTC	PET	Max S	Delta S	DR	Max D	Max Delta v	Conflict Angle	Conflict Type
40 St.232	0.30	3.60	5.66	5.55	-6.32	-6.32	3.08	-50.12	LC
40 St.232	1.30	3.30	7.15	2.17	-6.95	-7.05	1.12	-15.04	LC
40 St.232	1.20	2.20	2.61	1.15	-1.05	-1.38	0.58	-18.24	RE
40 St.232	0.30	2.60	5.33	4.54	-6.92	-6.90	2.48	12.09	RE
40 St.232	0.40	1.90	6.33	2.41	-6.75	-6.82	1.32	16.28	LC
40 St.232	1.30	3.00	4.48	3.43	-8.09	-8.15	1.90	-45.64	LC
40 St.232	1.20	1.20	0.56	0.44	-3.24	-6.13	0.24	9.13	RE
40 St.232	0.40	0.80	5.93	4.11	-3.35	-7.39	2.27	5.14	RE
40 St.232	1.20	2.20	6.88	2.96	-7.18	-7.31	1.48	21.2	LC
40 St.232	0.60	1.40	5.93	2.77	-0.04	-7.39	1.39	-10.21	RE
40 St.232	0.70	2.10	7.73	10.92	-0.22	-0.22	5.81	123.36	C
40 St.232	1.00	1.30	7.53	5.80	-0.07	-7.26	2.94	6.15	RE
40 St.232	1.20	2.50	7.26	13.13	-0.07	-0.40	7.18	-134.32	C
40 St.232	1.00	4.30	3.86	2.18	-0.02	-7.21	1.11	0.81	RE
40 St.232	0.50	1.90	4.18	3.71	-7.09	-7.09	1.91	0.02	RE
40 St.232	1.10	2.20	6.04	2.28	-0.42	-3.70	1.19	0.43	RE
40 St.232	1.30	2.20	3.93	3.35	0.38	0.38	1.86	51.66	LC
40 St.232	0.60	0.40	3.95	0.16	-1.05	-1.83	0.09	7.34	RE
40 St.232	1.20	2.30	8.02	8.02	-0.97	-3.28	4.13	33.52	LC
40 St.232	0.50	0.50	2.96	0.97	-1.52	-2.91	0.49	-0.20	RE
40 St.232	0.50	2.25	6.72	8.08	-0.19	-0.10	4.04	-104.68	C
40 St.232	0.90	0.60	6.72	8.08	-0.17	-0.10	4.04	-104.68	C
40 St.232	0.80	3.70	6.59	2.29	-7.59	-7.67	1.14	19.34	LC
40 St.232	1.20	2.30	3.54	1.18	-1.96	-1.96	0.67	-14.36	LC
40 St.232	0.90	1.40	2.98	2.51	-0.53	-7.39	1.29	0.70	RE
40 St.232	1.00	1.70	7.97	11.87	-0.03	-0.03	5.94	109.86	C
40 St.232	1.30	2.30	6.96	4.32	-0.41	-7.3	2.26	-20.31	RE
40 St.232	0.80	1.20	6.75	3.53	-0.79	-1.96	1.83	-18.76	RE
40 St.232	0.70	1.60	6.45	3.28	0.34	-7.49	1.64	-27.01	LC

40 St.232	0.80	0.60	5.03	3.18	-2.81	-2.81	1.81	-17.25	RE
40 St.232	0.80	1.50	6.04	3.36	-3.24	-7.57	1.86	-9.41	RE
40 St.232	0.50	2.90	6.57	2.16	-7.22	-7.3	1.08	18.81	LC
40 St.232	0.50	2.10	3.73	2.15	-7.78	-7.81	1.23	-49.24	LC
40 St.232	1.20	0.80	7.16	2.96	-7.86	-7.98	1.69	21.39	LC
40 St.232	0.50	1.90	6.72	8.08	-0.15	-0.15	4.04	-104.68	C
40 St.232	1.50	2.10	6.24	3.35	-2.53	-3.38	1.83	-0.740	RE
40 St.232	1.00	0.80	6.53	2.11	-7.26	-7.37	1.17	-17.76	LC
40 St.232	0.90	1.00	7.76	5.72	-0.23	-2.65	3.16	-3.20	RE
40 St.232	1.20	2.20	3.79	2.38	-3.83	-3.83	1.23	-9.28	RE
40 St.232	1.00	1.80	5.54	3.24	-7.35	-7.45	1.67	29.27	LC
40 St.232	1.10	1.80	4.83	4.32	-7.42	-7.4	2.16	13.86	RE
40 St.232	0.40	.60	7.44	10.15	-0.22	-0.22	5.79	89.64	C
40 St.232	1.30	3.70	4.34	1.42	-1.05	-2.22	0.71	0.24	RE
40 St.232	0.90	0.90	6.79	2.17	-7.28	-7.38	1.16	-17.9	LC
40 St.232	1.10	3.50	4.11	3.68	-4.15	-6.99	1.84	11.15	RE
40 St.232	1.20	4.30	7.64	7.54	0.45	-0.19	3.88	-10.59	RE
40 St.232	0.90	1.00	3.05	2.57	-3.64	-7.26	1.35	11.23	RE
40 St.232	0.30	0.80	4.16	3.18	-3.55	-6.92	1.59	0.88	RE
40 St.232	0.10	3.20	8.06	12.57	-0.06	-0.27	6.71	-109.44	C
40 St.232	1.00	4.70	6.58	2.27	-7.06	-7.24	1.19	16.91	LC
40 St.232	1.10	2.70	3.50	3.02	-0.07	-4.75	1.67	21.94	RE
40 St.232	1.30	2.30	2.18	2.18	-7.28	-7.28	1.21	-8.17	C
40 St.232	1.00	0.90	3.49	0.36	-0.45	-7.43	0.18	10.12	RE
40 St.232	1.20	1.90	6.35	6.35	-0.12	-4.54	3.62	-36.18	LC
40 St.232	0.50	2.60	7.63	7.54	-0.16	-7.23	3.88	-4.68	LC
40 St.232	0.40	2.70	6.24	3.35	-2.53	-3.38	1.83	-0.74	RE
40 St.232	1.30	2.30	6.53	2.11	-7.26	-7.37	1.17	0.67	RE
40 St.232	0.80	0.60	7.76	5.73	-0.23	-2.65	3.16	-3.24	RE

Table (D-2) SSAM Outputs of Surrogate Safety Measures of Conflicts at Bab-AL-Hussein Intersection

Trj File	TTC	PET	Max S	Delta S	DR	Max D	Max Delta V	Conflict Angle	Conflict Type
B.H.I.305	1.20	2.80	2.91	0.6	-0.11	-0.16	0.31	-0.25	RE
B.H.I.305	0.50	2.80	7.15	5.84	-0.25	-7.02	2.92	5.59	LC
B.H.I.305	0.80	2.50	5.33	1.66	-0.20	-7.76	0.95	-1.11	RE
B.H.I.305	0.10	1.90	3.91	1.37	-7.70	-7.81	0.70	-24.95	LC
B.H.I.305	0.60	2.60	4.19	3.13	-7.42	-7.42	2.48	-0.30	RE
B.H.I.305	0.90	2.20	4.07	2.06	-0.30	-1.89	1.72	-8.17	RE
B.H.I.305	1.10	1.80	6.68	5.8	-0.80	-7.47	3.31	-1.55	RE
B.H.I.305	0.70	1.50	4.17	3.77	-0.80	-2.07	2.07	31.24	LC
B.H.I.305	1.40	1.10	4.89	3.55	-3.28	-3.28	1.95	-0.85	RE
B.H.I.305	0.20	2.10	3.05	2.44	-4.02	-6.93	1.22	24.54	LC
B.H.I.305	1.50	2.50	3.26	1.3	-0.01	-6.89	0.67	-0.01	RE
B.H.I.305	1.10	1.50	3.61	0.56	-0.38	-5.95	0.29	-8.99	LC
B.H.I.305	0.80	3.30	2.76	2.25	-1.53	-3.82	1.28	25.04	LC
B.H.I.305	0.80	2.00	2.27	0.96	-0.02	-0.02	0.55	-18.63	RE
B.H.I.305	0.40	2.30	5.75	5.75	-2.07	-3.15	2.99	13.03	RE
B.H.I.305	1.30	2.30	2.55	2.44	-0.29	-1.19	1.36	32.8	LC
B.H.I.305	0.50	1.20	4.64	1.03	-7.64	-7.73	0.55	-3.79	RE
B.H.I.305	0.90	2.40	4.79	1.65	-3.13	-7.70	0.94	89.76	C
B.H.I.305	0.50	2.50	2.20	2.01	-2.07	-3.71	1.12	-0.09	RE
B.H.I.305	0.70	3.30	4.41	0.15	-0.13	-5.33	0.08	0.18	RE
B.H.I.305	0.90	0.90	7.16	4.27	-3.13	-3.49	2.43	86.45	C
B.H.I.305	0.10	2.10	6.54	5.74	-6.94	-6.96	2.87	50.31	LC
B.H.I.305	0.10	2.20	7.31	6.76	-0.23	-5.73	3.64	62.22	LC
B.H.I.305	0.80	1.50	5.14	2.37	-0.69	-5.92	1.18	5.25	RE
B.H.I.305	1.10	3.00	4.48	3.21	-3.34	-3.34	1.73	-19.92	LC
B.H.I.305	0.70	0.90	5.41	3.75	-2.90	-2.9	1.99	-6.89	RE
B.H.I.305	0.50	2.10	4.60	1.34	-2.49	-2.49	0.72	-0.03	RE
B.H.I.305	0.20	1.40	3.82	3.53	-0.33	-3.12	1.90	14.37	RE
B.H.I.305	0.70	2.40	1.78	0.73	-0.28	-3.94	0.37	-103.67	C
B.H.I.305	1.00	1.80	3.39	0.97	-1.08	-1.08	0.52	17.18	RE
B.H.I.305	0.30	2.20	6.97	2.75	-7.24	-7.37	1.44	-15.26	LC
B.H.I.305	0.70	5.00	2.00	0.53	0.78	-7.39	0.29	-0.11	RE
B.H.I.305	0.80	0.40	2.57	1.66	-0.10	-0.14	0.91	-35.89	LC
B.H.I.305	1.60	3.50	2.19	1.91	-6.72	-6.72	0.98	-0.03	RE
B.H.I.305	1.10	4.80	2.03	0.06	-0.05	-1.30	0.05	-1.48	RE

B.H.I.305	0.60	2.50	1.85	1.38	-3.31	-3.31	1.13	-0.49	RE
B.H.I.305	1.20	0.70	5.82	3.48	-0.12	-7.4	1.82	-0.92	RE
B.H.I.305	0.80	0.80	6.61	3.10	-1.00	-7.67	1.55	-0.89	RE
B.H.I.305	0.80	4.90	2.84	0.87	-0.31	-7.71	0.43	-0.45	RE
B.H.I.305	0.60	2.90	2.62	2.23	-3.12	-3.12	1.15	-100.27	C
B.H.I.305	1.10	1.40	3.69	2.73	-5.11	-5.11	1.36	89.45	C
B.H.I.305	1.20	2.50	8.08	3.87	-0.11	-3.19	2.97	6.84	LC
B.H.I.305	0.40	2.70	6.54	5.74	-6.94	-6.96	2.87	50.31	LC
B.H.I.305	1.10	1.60	4.85	3.47	-7.58	-7.58	1.78	-0.09	RE
B.H.I.305	0.90	3.30	1.93	1.81	-0.55	-4.01	0.94	0.78	RE
B.H.I.305	0.50	2.00	3.03	0.57	-7.74	-7.74	0.29	0.50	RE
B.H.I.305	0.30	3.00	4.66	0.65	-0.44	-5.35	0.34	6.98	LC
B.H.I.305	1.30	1.40	6.60	4.80	-6.72	-6.72	2.58	-2.25	RE
B.H.I.305	0.70	1.10	3.49	1.51	-3.19	-6.88	0.81	-100.41	C
B.H.I.305	1.10	1.60	2.18	0.11	-0.33	-2.10	0.06	0.18	RE
B.H.I.305	1.20	2.10	6.59	6.2	-0.51	-6.61	3.25	11.24	RE
B.H.I.305	0.90	0.40	2.53	2.25	-7.71	-7.74	1.13	-62.74	LC
B.H.I.305	0.80	1.80	6.04	1.43	-0.08	-7.55	0.74	3.15	RE
B.H.I.305	1.10	3.40	3.99	0.02	-7.17	-7.27	0.01	-5.75	RE
B.H.I.305	1.00	1.00	4.28	3.93	-0.06	-4.39	2.09	4.15	RE
B.H.I.305	1.20	1.60	4.35	3.47	-6.58	-6.58	2.80	-8.08	RE
B.H.I.305	0.80	2.40	3.33	0.77	-0.29	-7.77	0.38	-0.01	RE
B.H.I.305	1.60	2.90	2.78	2.78	-1.17	-6.82	1.48	-75.76	LC
B.H.I.305	0.30	3.40	2.54	0.98	-0.20	-0.45	0.8	3.39	RE
B.H.I.305	1.10	1.90	5.58	2.88	-3.33	-3.33	1.44	0.97	RE
B.H.I.305	0.90	2.10	3.90	3.41	-0.04	-0.58	1.71	-33.65	LC
B.H.I.305	1.10	1.70	4.30	1.82	-3.06	-3.06	0.91	-0.23	RE
B.H.I.305	0.90	1.90	3.24	2.00	-3.21	-7.19	1.00	10.71	RE
B.H.I.305	1.60	2.10	4.57	4.35	-0.15	-0.33	2.24	-23.8	RE
B.H.I.305	0.20	4.70	7.96	1.86	-0.32	-7.07	0.96	5.38	LC
B.H.I.305	1.20	1.00	4.32	0.77	-3.62	-3.62	0.41	12.69	LC
B.H.I.305	0.50	2.00	3.25	1.97	-3.13	-7.42	1.01	-2.19	RE
B.H.I.305	0.40	2.60	4.95	3.52	-0.09	-3.17	1.81	-1.24	RE
B.H.I.305	1.10	2.70	2.26	0.95	-0.16	-2.04	0.48	-0.19	RE
B.H.I.305	0.90	2.50	2.11	1.45	-1.65	-6.97	0.77	-0.69	RE
B.H.I.305	1.20	2.20	2.75	2.46	-5.60	-5.67	1.31	-71.98	LC
B.H.I.305	0.30	0.50	6.97	2.75	-7.24	-7.37	1.44	88.28	C
B.H.I.305	0.70	3.20	7.96	1.86	-0.32	-7.07	0.96	5.38	LC

Table (D-3) SSAM Outputs of Surrogate Safety Measures of Conflicts at Bab-AL-Mashhad Intersection

Trj File	TTC	PET	MaxS	Delta S	DR	Max D	Max Delta V	Conflict Angle	Conflict Type
B.M.I.316	1.80	1.80	3.90	3.90	-0.29	-0.95	2.01	40.48	LC
B.M.I.316	0.90	2.30	5.16	5.16	-1.91	-2.35	2.58	27.35	LC
B.M.I.316	0.80	1.90	1.66	1.56	-7.39	-7.39	0.82	-70.31	RE
B.M.I.316	1.40	2.60	2.33	2.33	-0.28	-1.98	1.24	0.55	RE
B.M.I.316	1.70	3.40	2.16	1.00	-0.29	-1.99	0.52	-103.20	C
B.M.I.316	1.50	2.30	4.86	4.05	-1.47	-3.93	2.15	0.02	RE
B.M.I.316	0.80	0.90	2.65	1.18	-6.64	-6.64	0.61	-8.82	RE
B.M.I.316	1.50	2.80	2.14	1.55	-3.86	-7.14	0.80	16.94	RE
B.M.I.316	0.90	3.90	2.25	2.17	-0.15	-7.14	1.15	16.54	LC
B.M.I.316	1.50	3.10	2.27	1.42	-3.01	-3.01	0.71	-7.30	RE
B.M.I.316	1.10	2.40	2.70	0.93	-3.01	-3.01	0.49	-20.53	LC
B.M.I.316	1.70	2.70	5.12	4.06	-6.70	-7.43	2.03	0.00	RE
B.M.I.316	1.60	1.10	2.19	1.78	-0.30	-2.20	1.01	47.32	LC
B.M.I.316	1.50	3.40	3.00	2.27	-0.04	-2.32	1.24	-0.34	RE
B.M.I.316	0.10	4.40	3.06	3.06	-0.94	-1.80	1.56	42.02	LC
B.M.I.316	1.50	3.30	4.03	1.05	-0.11	-1.74	0.54	0.05	RE
B.M.I.316	1.00	1.30	4.03	3.04	-0.31	-7.49	1.59	-0.09	RE
B.M.I.316	0.70	0.30	3.71	2.46	-7.35	-7.43	1.29	41.01	LC
B.M.I.316	0.50	1.00	3.88	2.32	-7.36	-7.46	1.21	-36.71	LC
B.M.I.316	1.70	2.10	4.30	3.63	-2.18	-2.29	1.82	-20.28	RE
B.M.I.316	1.50	3.60	3.68	2.52	-3.52	-7.28	1.32	14.49	RE
B.M.I.316	1.00	2.60	0.31	0.31	3.03	3.03	0.16	21.69	RE
B.M.I.316	0.90	1.00	2.47	1.05	-0.31	-2.19	0.52	-107.55	C
B.M.I.316	1.60	3.30	5.38	0.29	-0.18	-2.21	0.15	86.98	C
B.M.I.316	1.30	2.90	5.18	4.35	-0.95	-6.83	2.17	-7.94	RE
B.M.I.316	1.80	1.30	3.86	2.58	-0.24	-1.53	1.37	-27.15	LC
B.M.I.316	0.70	2.40	3.01	1.50	-0.03	-0.09	0.77	-35.3	LC
B.M.I.316	1.70	3.00	2.80	2.59	-0.39	-1.89	1.42	-1.44	RE
B.M.I.316	1.60	3.20	3.13	3.13	-0.29	-1.99	1.57	-0.01	RE

B.M.I.316	1.50	2.60	3.44	0.89	-0.29	-1.93	0.48	-10.26	RE
B.M.I.316	1.70	3.10	2.86	1.79	-4.62	-6.95	0.96	12.34	RE
B.M.I.316	1.40	3.10	2.57	1.01	-0.37	-2.71	0.56	12.56	LC
B.M.I.316	1.70	5.10	3.76	3.66	-6.86	-6.90	2.09	6.00	LC
B.M.I.316	1.50	2.50	4.13	3.14	0.22	-7.13	1.64	-0.19	RE
B.M.I.316	0.80	0.4	4.70	3.74	-0.29	-0.29	2.08	-101.41	C
B.M.I.316	1.70	2.20	1.86	1.12	-7.22	-7.22	0.59	-0.90	C
B.M.I.316	1.60	2.70	2.54	2.42	-0.39	-1.81	1.21	2.96	RE
B.M.I.316	0.90	1.40	3.82	2.77	-3.32	-3.32	1.39	14.87	RE
B.M.I.316	1.50	1.90	3.78	2.71	-0.08	-1.82	1.42	17.51	LC
B.M.I.316	0.80	2.20	3.21	3.17	-1.17	-6.16	1.76	-52.14	LC
B.M.I.316	1.20	2.50	5.17	4.84	-0.06	-5.71	2.46	5.40	RE
B.M.I.316	1.70	2.60	2.76	0.62	-0.04	-6.92	0.34	12.91	LC
B.M.I.316	1.10	2.50	3.81	1.19	-0.18	-2.58	0.68	-4.17	RE
B.M.I.316	1.60	5.30	2.98	2.74	-1.75	-1.76	1.43	0.00	RE
B.M.I.316	1.50	2.40	2.25	2.25	-0.02	-2.31	1.21	-52.92	LC
B.M.I.316	1.60	1.60	2.47	2.05	-0.11	-1.26	1.05	91.55	C
B.M.I.316	1.70	3.20	2.74	0.03	-0.02	-7.44	0.02	0.54	RE
B.M.I.316	1.10	1.60	3.11	2.18	-3.17	-3.15	1.14	-100.41	C
B.M.I.316	1.60	2.30	3.62	3.55	-0.12	-0.84	1.89	109.44	C
B.M.I.316	1.00	3.10	2.97	2.10	-6.51	-6.51	1.24	-12.32	RE
B.M.I.316	1.30	2.70	4.97	3.76	-0.36	-7.51	1.88	87.24	C
B.M.I.316	1.50	4.60	2.83	2.79	-0.63	-1.73	1.42	7.39	RE
B.M.I.316	0.60	0.50	1.93	1.55	-0.06	-0.06	0.86	-42.3	LC
B.M.I.316	1.70	3.00	3.33	2.71	-0.67	-2.73	1.42	28.96	LC
B.M.I.316	1.30	2.50	2.86	0.89	-3.31	-3.31	0.55	0.03	RE
B.M.I.316	1.00	2.70	2.11	1.58	-3.94	-3.94	0.83	9.28	RE
B.M.I.316	1.80	2.40	5.12	0.23	-0.36	-1.97	0.13	0.49	RE

Table (D-4) Summary of Some Information About Conflicts and Main Safety Indicators for 10 Trj Files for Each Site

Intersection	Trj.File	TTC Mean	PET Mean	Variance		Conflict Number			
				TTC	PET	Total	Crossing	Rear End	Lane Change
40 St.	40 St.227	0.86	2.24	0.22	0.73	79	11	43	25
	40 St.228	0.89	2.53	0.17	0.66	81	12	45	24
	40 St.229	0.85	2.57	0.20	0.71	82	11	44	27
	40 St.230	0.90	2.27	0.36	0.70	79	10	43	26
	40 St.231	0.88	2.37	0.15	0.74	82	11	45	26
	40 St.232	0.90	2.16	0.13	0.93	83	11	44	28
	40 St.233	0.87	2.26	0.23	0.65	78	9	46	22
	40 St.234	0.84	2.38	0.26	0.68	82	11	48	23
	40 St.235	0.83	2.28	0.21	0.72	81	11	44	26
	40 St.236	0.83	2.33	0.31	0.70	80	10	43	27
Bab-AL-Mashhad	B.M.I.314	1.19	2.34	0.19	0.90	57	9	31	17
	B.M.I.315	1.20	2.32	0.15	0.92	58	10	32	16
	B.M.I.316	1.31	2.51	0.16	1.10	57	9	30	18
	B.M.I.317	1.23	2.65	0.14	0.93	59	11	29	19
	B.M.I.318	1.26	2.61	0.12	0.85	54	7	29	18
	B.M.I.319	1.23	2.55	0.11	0.95	57	9	30	18
	B.M.I.320	1.21	2.40	0.16	0.89	58	11	28	19
	B.M.I.321	1.19	2.29	0.13	0.87	60	10	33	17
	B.M.I.322	1.27	2.44	0.17	0.91	56	10	30	16
	B.M.I.323	1.25	2.51	0.13	0.88	55	8	30	17
Bab-AL-Hussein	B.H.I.302	0.79	2.15	0.21	0.77	72	7	43	22
	B.H.I.303	0.82	2.41	0.12	0.83	74	8	43	23
	B.H.I.304	0.84	2.25	0.18	0.87	74	7	43	24
	B.H.I.305	0.82	2.20	0.14	0.98	73	7	44	22
	B.H.I.306	0.80	2.40	0.20	0.84	69	6	42	21
	B.H.I.307	0.82	2.22	0.19	0.91	71	6	41	24
	B.H.I.308	0.84	2.39	0.17	0.91	75	8	44	23
	B.H.I.309	0.84	2.18	0.20	0.39	71	6	43	22
	B.H.I.310	0.83	2.23	0.10	0.97	75	8	47	20
	B.H.I.311	0.82	2.17	0.13	0.89	76	8	46	22

Appendix (E)
Statistical Analyses of SSAM Outputs, Development Models, and Queue Length

Table (E-1) Correlation between Simulation and Field Conflicts (Bab-AL-Hussein)

Conflicts Types	Pearson correlation coefficient (r)	P-Value
Crossing	0.705[**]	0.000
Rear-end	0.565[**]	0.001
Lane-change	0.578[**]	0.001
Total Conflicts	0.791[**]	0.000

** Correlation is significant at the 0.01 level.

Table (E-2) Correlation between Simulation and Field Conflicts (Bab-AL-Mashhad)

Conflicts Types	Pearson correlation coefficient (r)	P-Value
Crossing	0.774[**]	0.000
Rear-end	0.659[**]	0.001
Lane-change	0.768[**]	0.000
Total Conflicts	0.863[**]	0.000

** Correlation is significant at the 0.01 level.

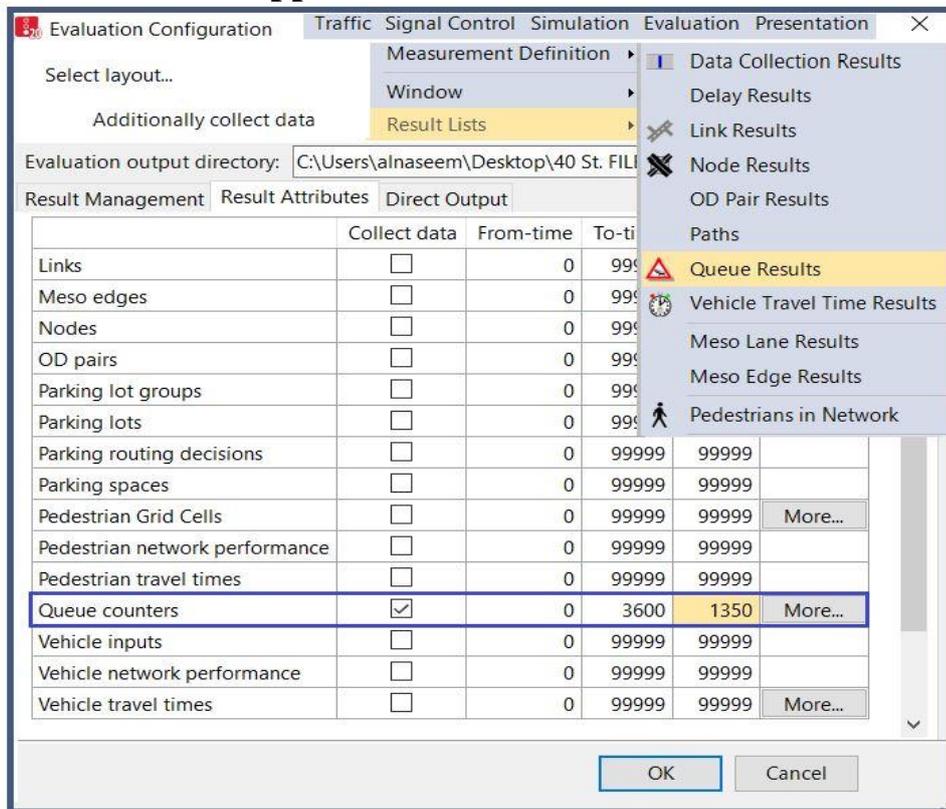| Descriptive Statistics											
Conflict Type	N	Range	Min.	Max.	Mean	Std. Dev.	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Observed Crossing Conflicts	32	3.00	.00	3.00	1.156	.766	.588	.179	.414	-.270-	.809
Simulated Crossing Conflicts	32	4.00	.00	4.00	1.968	1.256	1.580	-.146-	.414	-1.060-	.809
Observed Rear-end Conflicts	32	9.00	3.00	12.00	7.875	1.995	3.984	-.102-	.414	.220	.809
Simulated Rear-end Conflicts	32	9.00	5.00	14.00	10.718	2.051	4.209	-.623-	.414	.725	.809
Observed Lane-change Conflicts	32	7.00	2.00	9.00	3.968	1.804	3.257	.998	.414	.546	.809
Simulated Lane-change Conflicts	32	9.00	2.00	11.00	4.687	1.908	3.641	1.103	.414	2.652	.809
Observed Total Conflicts	32	15.00	7.00	22.00	13.968	3.922	15.386	.145	.414	-.612-	.809
Simulated Total Conflicts	32	20.00	7.00	27.00	17.281	4.144	17.176	-.138-	.414	.426	.809

Figure (E-1) Descriptive Statistics Analyses Related to validation the Simulation Approach in Estimation Safety at Signalized Intersections

Table (E-3)Average and Maximum Queue Lengths that Corresponding to Total Conflicts at 40 St. Intersection

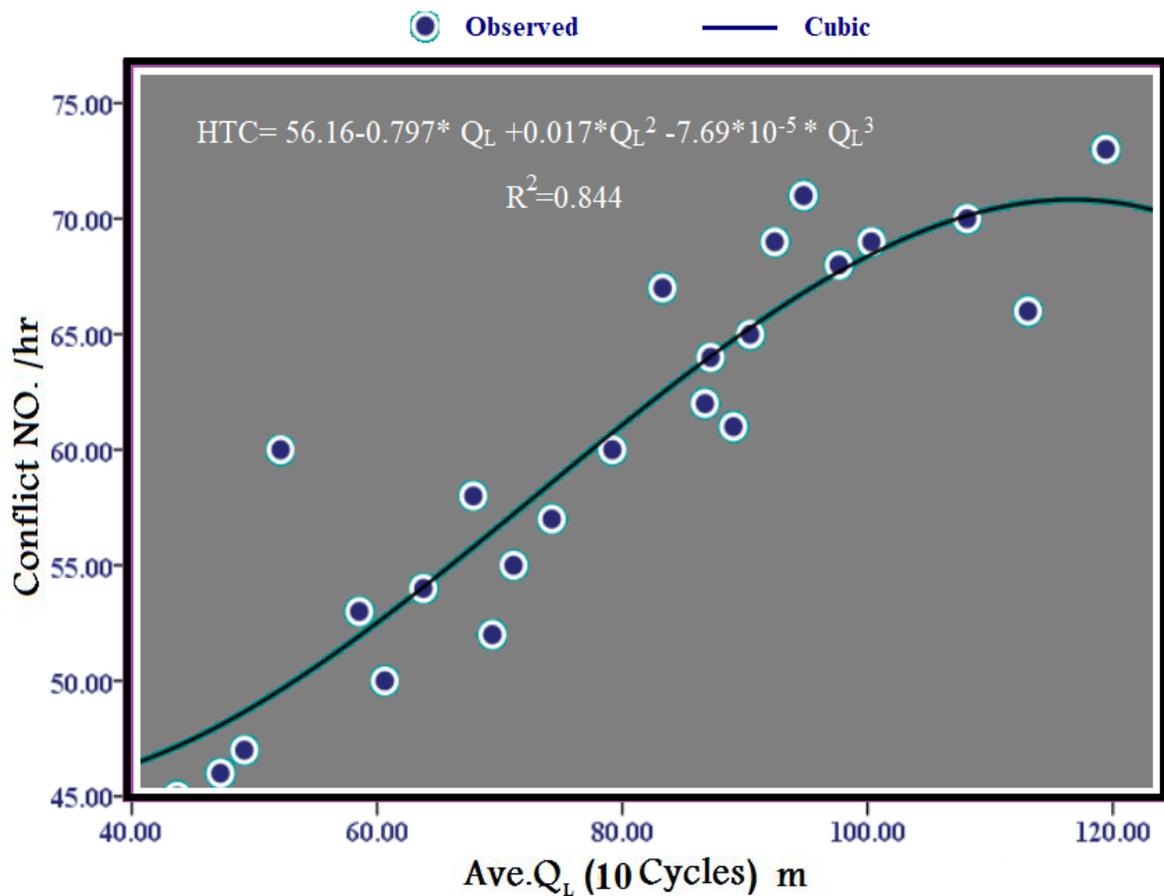| count	Sim. Run No.	Sim. Period	Ave. Q Len.	Max. Q Len.	Sim. Run No.	Sim. Period	Conflict No./hr
1	160	1350	58.29	82.27	227	3600	81
2	161	1350	54.80	72.12	228	3600	69
3	162	1350	42.69	61.64	229	3600	47
4	163	1350	46.71	68.30	230	3600	53
5	164	1350	52.28	70.29	231	3600	72
6	165	1350	40.05	62.60	232	3600	47
7	166	1350	45.40	67.25	233	3600	57
8	167	1350	52.62	78.01	234	3600	77
9	168	1350	54.12	78.89	235	3600	71
10	169	1350	47.02	61.07	236	3600	61
11	170	1350	51.99	68.56	237	3600	70
12	171	1350	57.07	81.40	238	3600	78
13	172	1350	53.04	72.47	239	3600	79
14	173	1350	43.72	69.78	240	3600	72
15	174	1350	49.55	78.80	241	3600	60
16	175	1350	45.40	67.51	242	3600	54
17	176	1350	49.27	75.94	243	3600	61
18	177	1350	43.29	79.40	244	3600	50
19	178	1350	54.03	67.25	245	3600	76
20	179	1350	55.29	75.83	246	3600	78
21	180	1350	47.08	67.55	247	3600	57
22	181	1350	52.67	79.00	248	3600	75
23	182	1350	43.43	74.73	249	3600	50
24	183	1350	52.95	66.83	250	3600	73
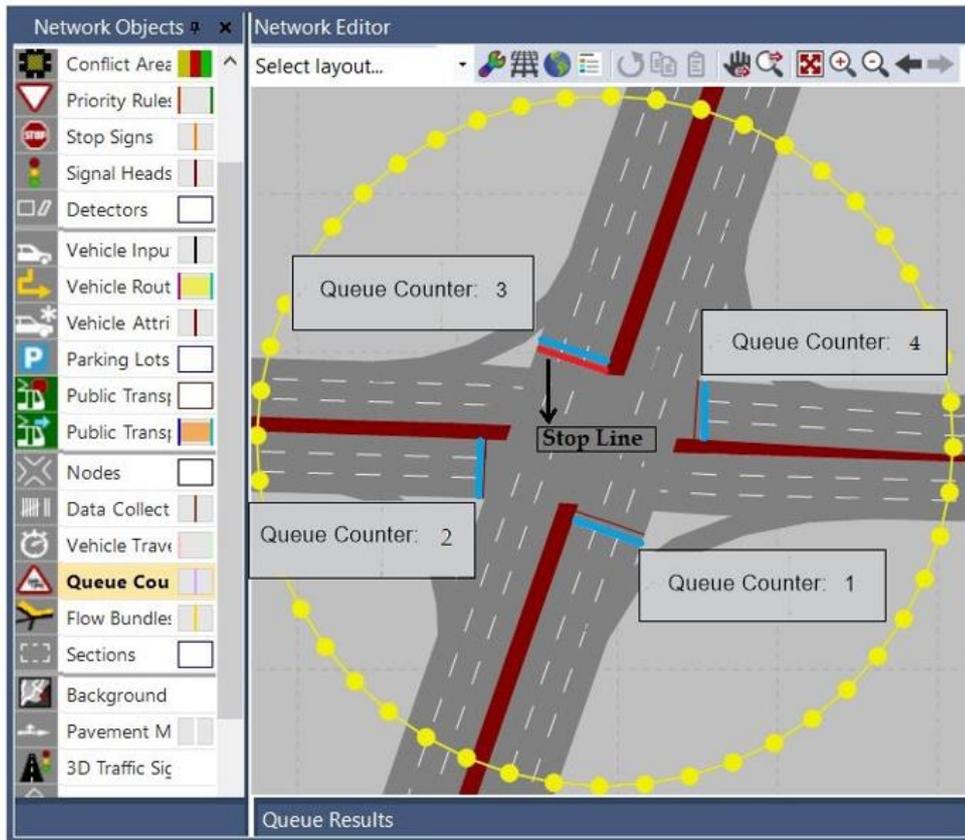
Figure (E-2) Determination the Start of Queue Counters at the Stop Line at approaches of the 40 St. Intersection

Figure (E-3) Evaluation Configuration of Queue Result

E-3

Table (E-4) Statistical Description of Dependent and Independent Variables Based on Queue Length to Predict Conflicts

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
QL(BHI)	24	75.73	43.70	119.43	79.147	4.342	21.273	452.560
HTC(BHI)	24	28.00	45.00	73.00	60.083	1.715	8.402	70.601
QL(BMI)	24	59.83	34.52	94.35	62.526	3.430	16.806	282.442
HTC(BMI)	24	21.12	35.88	57.00	46.948	1.297	6.356	40.399
QL(40 St.)	24	18.22	40.05	58.27	49.695	1.036	5.078	25.787
HTC(40 St)	24	40.00	41.00	81.00	61.875	2.492	12.213	149.158

Observed ● — Cubic

$$HTC = 56.16 - 0.797 * Q_L + 0.017 * Q_L^2 - 7.69 * 10^{-5} * Q_L^3$$

$$R^2 = 0.844$$

(Y-axis: Conflict NO. /hr; X-axis: Ave.Q_L (10 Cycles) m)

Figure (E-4) Regression Model to Predict Conflicts at Bab Al Hussein Intersection Based on Queue Length

المستخلص

السلامة المرورية هي جانب أساسي من جوانب هندسة النقل. خلاف ذلك ، لا توجد فائدة لمنشأ مروري يفتقر إلى السلامة. على الرغم من ذلك ، يتجاهل معظم مهندسي الطرق في البلدان النامية السلامة المرورية في تصاميمهم أو يتبنون الأساليب التقليدية التي تتسم بالضعف في تقييمهم لسلامة المرافق القائمة.

تقدم هذه الدراسة تقييماً للسلامة المرورية في ثلاثة تقاطعات مزودة بإشارات ضوئية في المناطق الحضرية لمدينة الحلة ، وذلك باستخدام (نهج المحاكاة) وهو أقتران احد نماذج محاكاة حركة المرور مع نموذج تقييم السلامة البديل (SSAM). تم استخدام نموذج المحاكاة (VISSIM ، الإصدار 10 ، 2020) لإنشاء ملفات المسار (trj) التي تحاكي الخصائص الهندسية ,حركة المرور والإشارة لتمثيل الحالة الحقيقية للمواقع المدروسة. تم جمع وتسجيل 88 ساعة من البيانات على مدار يومين متتاليين من أربع كاميرات ثبتت عند مقتربات التقاطعات. تم معايرة نموذج محاكاة VISSIM. ومن ثم تم تصدير الملفات إلى نموذج SSAM. تولت SSAM تحليل ملفات trj وحساب تدابير السلامة البديلة ، بما في ذلك وقت التصادم (TTC) ، وقت ما بعد التعدي (PET) ،معدل التباطؤ(DR) ، تم الاعتماد على TTC بشكل أساسي لتقييم شدة التعارضات وبالتالي تقييم مخاطر التقاطعات.

تم تصنيف التعارضات إلى ثلاثة أنواع رئيسية وفقًا لزاوية الاصطدام لكل زوج من المركبات المتضاربة الى تعارضات (نهاية خلفية RE ، تغير مسار LC، وعبورC) واستخراج عدد ، شدة ، وأماكن حدوث تلك التعارضات بواسطة نموذج SSAM. تم حساب معامل ارتباط بيرسون (PCC) بين تعارضات المحاكاة و الميدانية للتحقق من التعارضات المستخرجة من برنامجSSAM & VISSIM . أظهرت النتائج أن معايرة VISSIM خفض متوسط خطأ النسبة المطلقة (MAPE) لإجمالي التعارضات من 59٪ إلى 33٪. تراوحت القيم المثلى لمؤشري الأمان الرئيسيين TTC و PET اللتين كانتا أساس تحليل نموذج SSAM بين (1.8-1.5) ث و (4.7-

5.3) ث على التوالي. سادت التعارضات الخلفية في جميع المواقع حتى وصلت إلى 55٪ من جميع التعارضات.. وجد العدد الأكبر من التعارضات عند تقاطع شارع 40 ، تلاه تقاطع باب الحسين ثم باب المشهد (57.73.81) في ساعة الذروة. أظهرت الخرائط الحرارية أن المقترب الشرقي لتقاطع باب الحسين الأكثر خطورة ، في حين ان المقترب الغربي لتقاطع باب المشهد هو الأقل خطورة. طول طابور المركبات له تأثير مزدوج على السلامة ، فهو يزيد من تكرار التعارضات وفي نفس الوقت يقلل من حدة التعارضات ، وبالتالي تزداد التعارضات مع زيادة طول الطابور ، حيث أظهرت النماذج التنبؤية أن زيادة طول الطابور بنسبة 10٪ تؤدي إلى زيادة في تكرار التعارضات بنسبة 20٪.

خلصت الدراسة ، بالاعتماد على المحاكاة وتحليل SSAM ، قيم TTCI لتقاطع شارع 40 وباب الحسين كانت (0.86،0.82) على التوالي ، بحيث تم تصنيف كلاهما على أنهما تقاطعات عالية الخطورة. تم إجراء محاكاة افتراضية لتحسين سلامة تلك التقاطعات من خلال تغيير بعض الخصائص الهندسية ليتحولا على اثر ذلك التحسين الى تقاطعات معتدلة المخاطر ، بينما تم تصنيف تقاطع باب المشهد بقيمة (1.23 = TTCI) على أنه تقاطع معتدل الخطورة.

مقياس بديل لتخمين حالة الامان في تقاطعات مختلفة ذات إشارة ضوئية

رسالة

مقدمة الى قسم الهندسة المدنية في كلية الهندسة / جامعة بابل

كجزء من متطلبات نيل درجة الماجستير في الهندسة / الهندسة المدنية/ المواصلات

من قبل
حسيـــن مهـدي عبـد صالح
(بكالوريوس هندسة مدنية / 2000)

بأشراف
الاستاذ الدكتور/ حسين علـي عوض