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Identifying High Crash Signalized Intersections and Application of Highway Safety Manual Predictive Method to Reduce Crashes

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ABSTRACT

Road crash reduction depends on the precise identification of High Crash Locations (HCLs) and suggesting appropriate solutions and preventative measures. Though not all crashes are owing to defective characteristics of the roadway, a concentration of crashes at one location suggests that there may be a failure in the highway system. Identification of these HCLs can be achieved by detailed investigation of crash records, and further evaluations can then result in improvements that will decrease the number and severity of future crashes. The primary goal of this study is to identify HCLs in Duhok City and rank the signalized intersections using mathematical methods such as crash frequency method, crash rate method and critical crash rate method and identify possible treatments that reduce crashes at signalized intersections using the Highway Safety Manual. Distribution of crashes by type indicates that the rear end, angle, and sideswipe are common types of crashes that occur at these intersections. The results indicated that of intersections, Tax, Benavi 1, Benavi 2, Commerce, and Etite intersections are hazardous locations. The Highway Safety Manual (HSM) predictive method allows the design engineer in a road agency to estimate the measurable safety impacts of several design proposals and offer explanations for their design decisions. The results show that one approach/countermeasure to crash prevention may work effectively; however, a combination of approaches and/or countermeasures will have a greater impact. Furthermore, the results showed that there is a significant effect on the probable average crash frequency after all treatments applied at intersections.

KEYWORDS: Signalized Intersections; High Crash Locations; Predictive Method; Crash Modification Factors; Countermeasures

1 INTRODUCTION

Road Traffic Crashes (RTCs) place a heavy strain on the global economy because of the high rates of illness and mortality they cause. According to the World Organization's Global Status on Road Safety (2022) statistics, 1.35 million people die on the world's roadways, and millions more suffer injuries that need lengthy hospital stays or result in severe disability [1]. This has increased community and economic consequences. In addition, road traffic injuries were among the top three causes of death for the younger generation aged 15 to 29 years [1]. There are numerous causes of crashes. The Federal Highway Administration (FHWA) lists driver, vehicle, roadway and environmental factors as the primary causes of crashes [2]. At signalized intersections, there are typically a number of important factors that influence crash occurrences, such as traffic characteristics, traffic control measures, geometric design and characteristics. Although a crash may be known as driver error, fatal and serious injury crashes frequently occur because drivers come across road hazards. Hence, increasing the need for roadway improvements to reduce crashes is very important. Road crash reduction depends on the precise identification of High Crash Locations (HCLs) and the recommendation of appropriate solutions and preventative measures. By carefully examining crash records, it is possible to identify these HCLs, and further evaluations can lead to changes that will lessen the frequency and severity of future crashes [3]. The observed number of crashes and crash rate technique are frequently used to recognize and rank sites and suggest suitable countermeasures [4].

One of the approaches to improve road safety is to find unsafe places on a road network. Hence, it is very essential to determine these dangerous locations in provision for applying protective measures [5]. Analytical and reasonable procedure for the safety improvement, including crash prediction methods for evaluating the safety of a road segment and intersection design and for assessing the safety benefits of proposed or implemented countermeasures are documented in the Highway Safety Manual (HSM). Fundamentals to the tasks of screening the road network for locations with a potential for safety improvements, predicting the expected crash frequency, selection of countermeasures and evaluation of safety improvements are Safety Performance Functions (SPFs) and Crash Modification Factors (CMFs) [4].

The predictive method has been applied by many researchers in the United States and global since the publication of the HSM in 2010. Historical crash data were used to identify hazardous intersections and mitigate road safety problems at Lampang Municipality area in Thailand [6]. Improvements were applied to a four-legged signalized intersection which had a wide intersection area and insufficient sight distances. The authors suggested to apply different countermeasures to improve safety including; designing channelization to discourage improper movement and providing driving guidance path for right-turn maneuver. The authors found that, the black spot improvement can be an effective engineering approach to relieve the safety problems at critical intersections.

Abuaddous et al. (2022), focused on the identification and ranking of crash black spots in selected Jordanian localities. Using crash data of 3 years for 30 segments at 7 intersections in the city of Amman/Jordan, and based on several methods such as: crash rates, crash frequency and crash severity index, the locations were ranked based on their safety level. The results revealed that recognizing the high black spot locations contributes to reduce probable traffic crashes [7]. Crash prediction research was carried out in Belagavi City/India [8]. The authors analyzed three years of crash data (2015-2017). The main objective was to assess the effect of the various factors for road crashes by collecting crash data, road inventory survey, traffic volume and speed data. Severity index method, ranking method and GIS techniques were used to identify the high crash locations. The authors identified crash black spot in the nominated study section and some counteractive measures were made to reduce future crashes and to improve the highway system. It was also found that a greater number of crashes occurred due to rash driving and inattention of traffic rules [8]. Treeranurat and Suanmali (2021) aimed to identify black spots and develop a model depending on the levels of crash severity. This model improved by using Equivalent Crash Number (ECN) and Upper Control Limit (UCL). For this model the authors collected the crash data from five rural roads in Thailand during three years. The results showed that most crashes were rear-end type due to exceeded speed limits based on the results of black spots recognized in the study [9]. Erdogan et al. (2008) conducted a study in Turkey to assess crash distribution in a highway in Afyonkarashiasar city. The authors utilized two different ways of kernel density analysis to identify hotspots that reflect problematic locations such as intersections [10].

Instead of using total crash counts at sites, some researchers have recommended using crash reduction potential (CRP) to identify black spots [11–14]. These methods depend on the principle that "excess" crashes over those anticipated from similar locations can be prohibited by applying suitable treatments, and hence the possible reduction is a well process for identifying high crash locations (site has larger than expected numbers of crashes). So far, other researchers [15–17], used total crash counts for sites with large traffic volumes to identify sites with larger than expected numbers of crashes. Others, emphasized on the significance of crash severity and costs [18]. Several studies applied HSM predictive method to enhance road safety and to make the greatest results in order to decrease the frequency and severity of traffic crashes [19, 20, and 21].

The main goal of this study is to identify high crash signalized intersections and associated potential countermeasures to reduce crashes using HSM predictive method. The particular objectives of this investigation include: developing a descriptive study of the crash data for the study area including 22 signalized intersections in a period of 2017-2021 to focus only on those crashes that are signalized intersection related and to isolate the crashes by type. It should be noted that the approach to only consider multi-vehicle crashes (angle, rear-end and sideswipe) was selected based on the initial analysis of the data set of all intersection related crashes which revealed that right angle crashes, rear-end and side swipe are the primary crash type at signalized intersections. It also covers identification and ranking of high crash locations (intersections) for urban road network of Duhok city using mathematical methods such as crash frequency method, crash rate method and critical crash rate method and identifying and suggesting potential countermeasures to reduce crashes by application of CMF and predictive method of HSM.

2 METHODOLOGY AND DATA COLLECTION

To identify high crash locations in Duhok city and to propose associated potential countermeasures to reduce crashes mathematical methods and predictive method of HSM were applied. This process requires an overview of the types of data required for the identification of intersection safety issues.

2.1 Study Area Description

A list of 22 signalized intersections in Duhok city was used for achieving the objectives of this study as shown in Figure 1. It is important to note that there is no criteria in numbering the intersections shown in the figure. Each intersection in the list was visited by field survey to assure the accessibility of relevant data and collect the required data. The traffic control at the intersections was signal control. Related data that were available for this research cover the study period of 2017-2021. Only high crash intersections with the most likelihood for crash reduction were used for further review to evaluate the crash reduction benefits of implemented countermeasure.

2.2 Data Collection

The safety analysis of signalized intersections' procedure requires the collection of crash data for each site. Besides the historic crash information, effective HCLs identification and application of predictive methods requires geometric characteristic data, speed limit and traffic volume data. The data collection effort for these types of data is clarified in the following sections.

2.2.1 Crash Data

Crash data were collected for the year 2017 to 2021 from Duhok Traffic Directorate crash information database [10]. For assigning crashes to an intersection, crashes that happened within the physical limits (intersection functional area) of the intersections along with related crashes located on the intersection approach legs within 100 m were involved in the analysis [4]. Crash data were filtered to select only angle crashes, rear-end crashes and sideswipe crashes that occurred at each site. Crashes included in the dataset were only those that involved multiple vehicles at signalized intersections. After filtering and cleaning the crashes for the nominated intersections from crash database, nearly 404 total crashes were identified to be included in the analysis.

2.2.2 Traffic Volume Data

For the methods in the HSM, the data of traffic volume used are Annual Average Daily Traffic (AADT). For each site, traffic volumes were collected for the 5 years, covering the same number of years of available crash data. Video recording technique and manual counting of vehicles for the morning peak hour was used to calculate the traffic volume data for the intersections of missing information for the year of study. It is important to note that the growth factor of 3% was used in estimating traffic volume for the years of missing data over the study period [22]. This data of volume was converted to AADT to be used in the analysis.

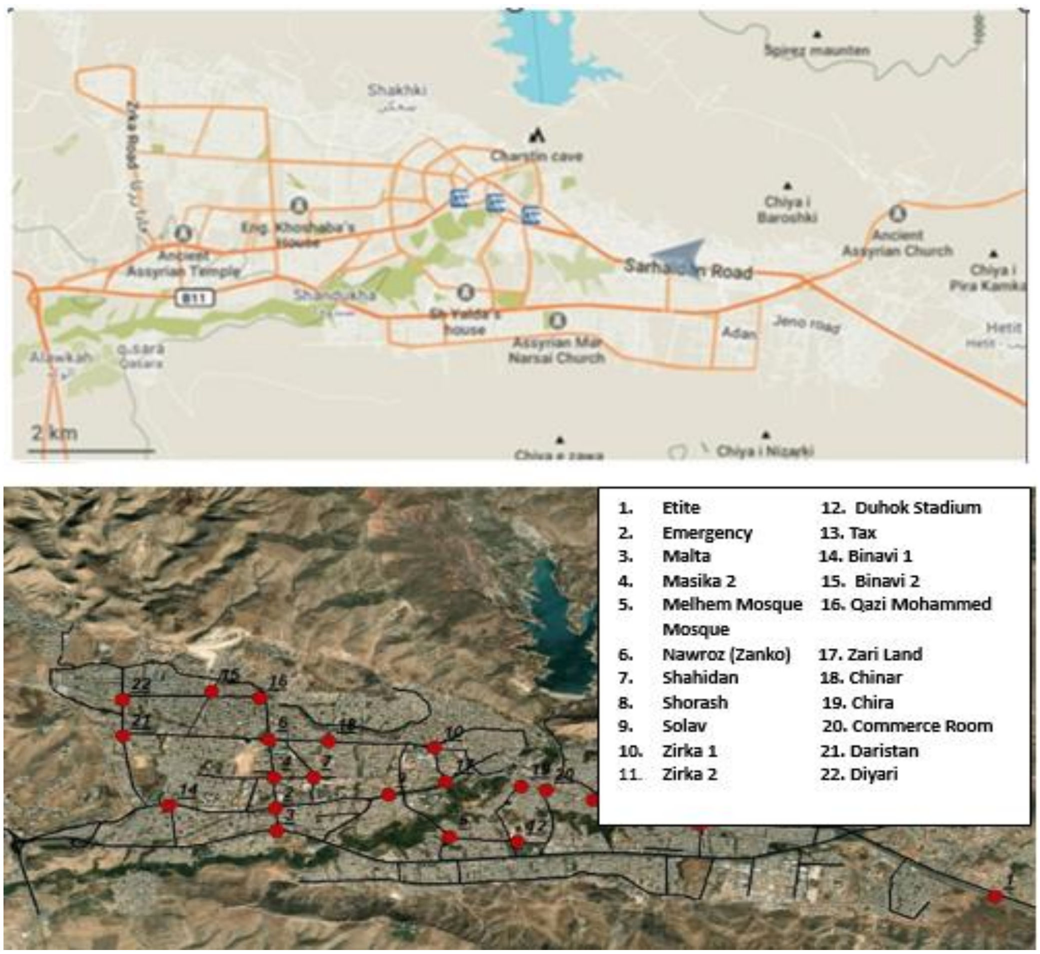

Figure 1. Study area

This data of volume was converted to AADT by dividing the volume of peak hour by peak hour factor and appropriate value of K which ranges from 8% to 12% for urban facilities [4] and indicates the proportion of volume going on during the peak hour as shown in the following equations. The average value of K=10% was used in this study.

$$PHF = \frac{Peak\ hour\ volume}{(4 \times peak\ 15\ minutes\ volume)} \quad (1)$$

$$DHV = \frac{Peak\ hour\ volume}{Peak\ hour\ factor} \quad (2)$$

$$AADT = \frac{DHV}{K} \quad (3)$$

$$AADT\ future\ = AADT\ current\ + (growth\ factor \times AADT\ current) \quad (4)$$

Where;

PHF = Peak hour factor

DHV= Design Hourly Volume (veh/hr)

AADT: Annual Average Daily Traffic (veh/day)

K= Proportion of AADT occurring in the peak hour

AADT future = Annual Average Daily Traffic for future years (veh/day)

AADT current = Annual Average Daily Traffic for current years (veh/day)

In the predictive model, two values are required for each intersection. These are the AADT of the major street and the AADT of the minor street.

2.2.3 Geometric Characteristics Data

Intersection geometric data relate to information about the physical features of each site. For signalized intersections, data collection was required for each individual approach of the selected intersections. The geometric features that have been collected include, number of lanes (left turn, through, and right turn), approach width, existence of shared lane, presence of median and type of intersection. Speed limits were obtained from reviewing the observed speed limit signs at each signalized intersections approaches from field survey.

2.3 Identifying High Crash locations

The performance measure methods for signalized intersections were used to identify and rank hot spots or high crash locations. The mathematical methods that were used for this step include average crash frequency, observed crash rate and critical crash rate [4]. Gradual process for applying the performance measures in this research study are provided in the following sections according to requirements of HSM.

2.3.1 Average Crash Frequency

This method is simple and only is rest on the number of crashes by crash type (angle, rear-end and sideswipe) without the effect of exposure (traffic volume). Firstly, crash data from Duhok city crash database which covers information on crashes that happened during the 5-year period (2017-2021) of interest as provided by Duhok police [22] were filtered to select only angle crashes, rear-end crashes and sideswipe crashes that occurred at each site. Consequently, the sites can be ranked in descendent order by the number of total crashes. This method can be used to choose a preliminary group of sites with high crash frequency for further study.

2.3.2 Crash Rate

The crash frequency method is not enough to identify HCL and the effect of traffic volume should be considered. Observed crash rate method is based on the effect of exposure (traffic volume) through dividing the entire number of crashes for each type (angle, rear end and sideswipe) by traffic volume which includes the frequency of vehicles approaching the intersection (all legs), measured as million entering vehicles (MEV). The observed crash rate can be calculated based on the following steps:

$$TEV = \sum AADT\ of\ all\ approaches \qquad (5)$$

$$MEV = \frac{TEV}{1000000} \times n \times 365 \qquad (6)$$

$$Ri = \frac{N_{observed(by\ crash\ type)}}{MEV} \qquad (7)$$

Where:
TEV = Total entering vehicles per day.
MEV = Million entering vehicles.
n= Number of years of crash data.
Ri = Observed crash rate.
N= Number of crashes in the study period.

2.3.3 Critical crash rate

To decide which signalized intersection is HCL, the observed crash rate should be compare with critical crash rate for each signalized intersection. Intersections that their crash rate exceed critical rate are need for more assessment. The critical crash rate is based on the average crash rate at alike sites, traffic volume, and a statistical constant that denotes an anticipated confidence level. To calculate weighted average crash rate per population for all signalized intersections by crash type all sites were classified to groups based on number of legs and similar range of traffic volume.

$$Ra = \frac{\sum_{i=1} TEV \times Ri}{\sum_{i=1} TEV} \quad (8)$$

$$Rc = Ra + \left[P * \sqrt{\frac{Ra}{MEV}}\right] + \left[\frac{1}{2*MEV}\right] \quad (9)$$

Where

Rc = Critical crash rate for intersection.

Ra = Weighted average crash rate for reference population.

P = P-value of 1.645 which matches to a 95% confidence interval.

Final step is to compare crash rates that are observed with critical crash rates at each site. Any signalized intersection having observed crash rate larger than the critical crash rate is considered for further evaluation and identifying countermeasures that will reduce crashes.

2.4 Application of the HSM Predictive Method

The predictive method delivers the way to estimate the predicted average crash number of an individual site (signalized intersection). The estimation is for a specified time period (in years) in which the geometric design and traffic control properties are fixed and traffic volumes (AADT) are known or anticipated. The predictive models in the HSM include applying regression models, recognized as SPFs, combined with CMFs and calibration factors to remodel it to local conditions. The predictive method utilizes equations known as Safety Performance Functions (SPFs) to estimate the predicted average crash number as a function of traffic volume [4], [23]. The HSM predictive methodology enables the evaluation of the safety effects of alternative design suggestions by giving the required SPFs and CMFs for intersections on urban arterials. An extensive range of CMFs is offered in the HSM for use in selecting countermeasures. The expected number of crashes at a site are first estimated for a set of base conditions using the reported base SPFs. Crash modification factors reported in the HSM, are then utilized to adjust the base model prediction to consider the effects of conditions unlike the base model conditions.

2.4.1 Predicted Crashes for Base Condition

The influence of traffic volume on predicted crash number for intersections cover through SPFs, however, the impact of geometric and traffic control features is covered via CMFs. Each of the SPFs for intersections considers the belongings for the AADTs on the major and minor road legs. The focus of this research is for Multiple–vehicle crash type (angle, rear-end and sideswipe). Hence, SPFs for intersections multiple-vehicle crashes have to do with as follows;

$$Nspf = exp\,(a + b \times ln\,(AADT\,maj) + c \times ln(AADT\,min)) \quad (10)$$

Where;

AADTmaj = average daily traffic volume (vehicles/day) for major road (both directions of travel added together)

AADTmin = average daily traffic volume (vehicles/day) for minor road (both directions of travel added together)

a, b, c = regression coefficients.

2.4.2 Predicted Crashes for Site Condition and Crash Modification Factors

The effects of separate geometric features and traffic control characteristics of intersections are denoted in the predictive models by CMFs. HSM presents CMFs applicable to types of intersections, access management appearances close to intersections, basics of intersection design, and traffic control and operational fundamentals of intersections. CMF1i to CMF6i are applied to multiple-vehicle crashes [4]. The general equation of predictive method for an intersection is;

$$Npredicted = Nspf \times (CMFi1 \times CMFi2 \times CMFi3 \times \ldots CMFix) \times Ci \qquad (11)$$

Where;

Npredicted = predicted average crash frequency of the intersection for the nominated year.

Nspf = predicted average crash frequency of intersection related crashes for base condition.

CMFix = Crash Modification Factors related to the site type and specific geometric and traffic control characteristics

Ci = Calibration factor for intersections developed for use for a particular geographical area. It is a factor to alter crash frequency estimations formed from a safety prediction process to estimated local conditions.

2.4.3 Calculation of Calibration Factor

HSM includes predictive models which involve SPFs, CMFs and Calibration factors, and have been developed for segments of roadways and intersection types. The SPFs are the base of the predictive models and were developed in HSM associated research from the greatest comprehensive and reliable existing data sets. Therefore, predictive models to deliver results that are expressive and accurate, it is vital that the SPFs be calibrated for use in each location. Some HSM users may select to develop SPFs with data from their particular jurisdiction for use in the predictive models in place of calibrating the SPFs.

It is important to note that development of SPFs requires to identifying a group of reference sites with approximately similar characteristics to the sites (intersections) that will be considered for treatment application. Therefore, for this study, due to unavailability of reference sites to develop SPF regression model, the default value of regression coefficients from HSM were used with the use of local AADT values. Then, the calibration factor was developed for intersections in Duhok city to adjust crash frequency estimations obtained from a safety prediction method to local conditions. Calibration factor (Ci) is the relation of the observed crash frequency to the predicted crashes, as presented in the following formula.

$$Ci = \frac{\sum_{all\ sites} Observed\ Crashes}{\sum_{all\ sites} Predicted\ Crashes} \qquad (12)$$

2.4.4 Countermeasures for HCL

CMFs calculate the variation in predicted average crash frequency at a site as a consequence of applying a specific treatment. In this study CMFs for some of the treatments that are available in the HSM and were used to identify their effects. However, for some others, the CMF is not offered nonetheless a trend about the possible change in crashes or human behavior is identified [9]. Treatments that were used are categorized into four categories; treatments related to intersection types, treatments related to intersection design elements, treatments associated to traffic control and operational elements of intersections and treatments associated to access management. After the possible treatments were selected, predicted crashes calculated by the following equation;

$$Npredicted\ after\ treatment = [CMF \pm (2 \times standard\ error)] \times Npredicted\ before\ treatments \qquad (13)$$

3 RESULTS AND DISCUSSION

The initial step in the analytical process involved disaggregating the roughly 1387 crashes that occurred during the 5-years period (2017-2021) in Duhok city road network (roadway segment and intersections) to focus only on those crashes that are signalized intersection related and to isolate the crashes by type. It should be noted that the approach to only consider multi-vehicle crashes (angle, rear-end and sideswipe) was selected based on the initial analysis of the data set of all intersection related crashes which revealed that right angle crashes, rear-end and side swipe are the primary crash type at signalized intersections. These crashes were linked to 404 crashes out of 473 total crashes that occurred at 22 signalized intersections in Duhok city as shown in Figure 2. The distribution of right-angle crashes, rear-end and side swipe crashes for each individual intersection is provided in section 3.1.

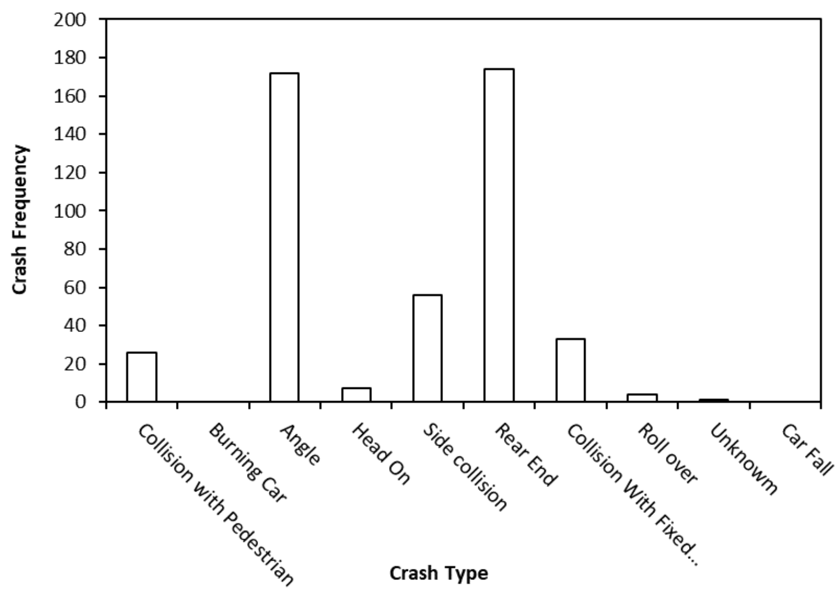

Figure 2. Distribution of crashes by type

Distribution of crash frequency by type given in Figure 2 indicates that the rear end, angle, and side swipe are common type of crashes in which rear-end crashes account for 36.8%, angle crashes represent 36.4% and side swipe crashes constitute 12% of total crashes. This is because the driver's decision has a significant influence on the probability of rear-end and angle crashes at signalized intersections. Generally, right angle crashes happen when drivers are unable to safely clear the intersection before the conflicting movements get the green indication. Moreover, improper signal timing, excessive speed, and slippery pavement could all play a role in angle crashes at signalized intersections When drivers suddenly stop, they cause a rear-end crash. Inappropriate approach speeds, inadequate signal visibility, unanticipated lane changes on approach, narrow lanes, excessive speed, and slippery surface may also be contributing factors in rear-end crashes.

3.1 Identification of High Crash Signalized Intersections-Mathematical Methods

Identification of dangerous sites is based on the analysis of traffic crashes, their consequences, and road and traffic characteristic. Mathematical methods were used to rank all 22 signalized intersections. It is important to note that the information regarding the cost for crash severity or type are not available, therefore only the before mentioned procedures were used for ranking of the intersections. Ranking of the 22 sample intersections by angle crash frequency method and rear-end and side swipe crash frequency method in terms of number and percentages is presented in Table 1. The results show that Tax intersection has the highest rank according to angle crashes, while both Commerce and Etite intersections have the highest rank according to rear-end and side swipe crashes.

Table 1: Intersections ranking with OBSERVED crash frequency method

No.	Name of Intersection	Angle Crashes		Name of Intersection	Rear-end and side swipe Crashes	
		NO.	%		NO.	%
1	Tax	23	13.37	Commerec of Chamber	23	10.64
2	Etite	21	12.2	Etite	23	10.64
3	Binavi 1	18	10.46	Tax	21	9.72
4	Zari land	16	9.3	Binavi 1	20	9.25
5	Duhok Stadium	15	8.72	Shahidan	19	8.79
6	Binavi 2	14	8.13	Newroz (Zanko)	14	6.48
7	Commerec of Chamber	10	5.81	Zari land	13	6.01
8	Newroz (Zanko)	8	4.65	Chra	10	4.62
9	Zirka 2	8	4.65	Diyary	10	4.62
10	Malta	7	4.06	Emergency	9	4.166
11	Chra	5	2.9	Malta	8	3.7
12	Diyary	5	2.9	Daristan	6	2.77
13	Qazi Muhammad Mosque	4	2.32	Masik 2	6	2.77
14	Daristan	3	1.74	Melhem mosque	6	2.77
15	Melhem mosque	3	1.74	Qazi Muhammad Mosque	5	2.31
16	Shahidan	3	1.74	Zirka 2	5	2.31
17	Zirka 1	3	1.74	Duhok Stadium	4	1.85
8	Chinar	2	1.162	Shorash	4	1.85
19	Emergency	2	1.162	Binavi 2	3	1.38
20	Shorash	1	0.581	Solav	3	1.38
21	Solav	1	0.581	Chinar	2	0.925
22	Masik 2	0	0	Zirka 1	2	0.925

Ranking of the 22 sample intersections angle crash rate method and rear-end and side swipe crash rate method is shown in Table 2 and Table 3 respectively. The tables summarize TEV (the total entering volume is a totality of the major and minor street AADT) and MEV (million vehicle entering each intersection). TEV is converted to MEV and crash rate for each intersection is found (refer to section 2.3.2). Ranking of the intersections depending on their angle crash rates indicates that the Benavi 2 intersection has the highest rank, the second rank is related to Etite intersection and the third rank is related to Tax intersection. For rear-end and side swipe crashes, Masik2 has the highest rank followed by Commerce intersection and the third rank is related to Etite intersection. The results confirm the importance of considering exposure (traffic volume).

Ranking of the all 22 intersections by critical crash rate method for angle crashes and rear-end and side swipe crashes is summarized in Table 4. The critical crash rate for each intersection is compared to the crash rate that is observed to decide if more evaluation of intersection is necessary. Each intersection with an observed crash rate larger than the comparable critical crash rate is considered for additional review. The high crash intersections are highlighted in grey color. The intersections considered for further review by angle critical crash rate are Binavi1, Binavi 2 and Etite intersections. According to rear-end and side swipe critical crash rate method, Binavi 1, Commerce, and Tax are high crash locations.

Table 2: Intersections rankings with crash rate method of observed angle crashes

NO	Name of Intersection	TEV (Sum of all leg traffic volume)	MEV (million vehicle entering each intersection)	Ri (Observed Crash Rate)
1	Binavi 2	20279	37.009175	0.3783
2	Etite	38324	69.9413	0.3002
3	Tax	57752	105.3974	0.2182
4	Dohuk Stadium	37875	69.121875	0.2170
5	Zrka 2	24493	44.699725	0.1789
6	Binavi 1	56033	102.260225	0.1760
7	Zariland	53194	97.07905	0.1648
8	Chinar	6872	12.5414	0.1595
9	Commerce	36289	66.227425	0.1509
10	Zanko (Nawroz)	43146	78.74145	0.1016
11	Malta	47099	85.955675	0.0814
12	Diyary	38429	70.132925	0.0713
13	Melhem Mosque	23572	43.0189	0.0697
14	Daristan	24657	44.999025	0.0667
15	Chra	57601	105.121825	0.0476
16	Shahidan	38416	70.1092	0.0428
17	Qazi Mohammad Mosque	70730	129.08225	0.0309
18	Zrka 1	71194	129.92905	0.0231
19	Emergency	68112	124.3044	0.0161
20	Showrash	34753	63.424225	0.0158
21	Sulav	47064	85.8918	0.0116
22	Masik 2	3098	5.65385	0

Table 3: Intersections rankings with crash rate method of observed rear-end and side swipe crashes

No	Name of Intersection	TEV (Sum of all leg traffic volume)	MEV (million vehicle entering each intersection)	Ri (Observed Crash Rate)
1	Masik 2	3098	5.65385	1.0612
2	Commerce	36289	66.227425	0.3473
3	Etite	38324	69.9413	0.3288
4	Shahidan	38416	70.1092	0.2710
5	Tax	57752	105.3974	0.1992
6	Binavi 1	56033	102.260225	0.1956
7	Zanko (Nawroz)	43146	78.74145	0.1778
8	Chinar	6872	12.5414	0.1595
9	Diyary	38429	70.132925	0.1426
10	Melhem Mosque	23572	43.0189	0.1395
11	Zariland	53194	97.07905	0.1339
12	Daristan	24657	44.999025	0.1333
13	Zrka 2	24493	44.699725	0.1119
14	Chra	57601	105.121825	0.0951
15	Malta	47099	85.955675	0.0931
16	Binavi 2	20279	37.009175	0.0811
17	Emergency	68112	124.3044	0.0724
18	Showrash	34753	63.424225	0.0631
19	Dohuk Stadium	37875	69.121875	0.0579
20	Qazi Mohammad Mosque	70730	129.08225	0.0387
21	Sulav	47064	85.8918	0.0349
22	Zrka 1	71194	129.92905	0.0154

Table 4: Intersections ranking with critical crash rate method of angle and rear-end and side swipe crashes

No	Name of Intersection	Angle Crashes			Rear-end and Side Swipe Crashes		
		Ri (Observed Crash Rate)	Rc (Critical Crash Rate)	HCLs (Ri>Rc)	Ri (Observed Crash Rate)	Rc (Critical Crash Rate)	HCLs (Ri>Rc)
1	Binavi 1	0.1760	0.1056		0.1956	0.1422	
2	Binavi 2	0.3783	0.2816		0.0811	0.2271	
3	Chinar	0.1595	0.4017		0.1595	0.3368	
4	Chra	0.0476	0.1049		0.0951	0.1414	
5	Commerce	0.1509	0.2191		0.3473	0.3409	
6	Daristan	0.0667	0.2692		0.1333	0.2160	
7	Diyary	0.0713	0.1525		0.1426	0.2472	
8	Dohuk Stadium	0.2170	0.2591		0.0579	0.2082	
9	Emergency	0.0161	0.1010		0.0724	0.1368	
10	Etite	0.3002	0.2168		0.3288	0.3379	
11	Malta	0.0814	0.2492		0.0931	0.1994	
12	Masik 2	0	0		1.0612	1.8623	
13	Qazi Mohammad Mosque	0.0309	0.0492		0.0387	0.1746	
14	Shahidan	0.0428	0.2166		0.2710	0.3378	
15	Showrash	0.0158	0.2210		0.0631	0.3435	
16	Sulav	0.0116	0.0561		0.0349	0.1879	
17	Tax	0.2182	0.2411		0.1992	0.1921	
18	Zanko (Nawroz)	0.1016	0.1485		0.1778	0.24199	
19	Zariland	0.1648	0.2443		0.1339	0.19497	
20	Zrka 1	0.0231	0.1000		0.0154	0.1357	
21	Zrka 2	0.1789	0.2389		0.1119	0.3659	
22	Melhem Mosque	0.0697	0.2719		0.1395	0.2184	

3.2 Application of HSM Predictive Method

The overall formula of the predictive method (refer to (11)) and steps identified in section 2.4, were applied to estimate the predicted average crash number of a specific intersection. Signalized intersections having observed crash rate greater than the critical crash rate are considered for further review and identifying countermeasures that will reduce crashes. These intersections are: Etite, Binavi 1, Binavi 2, Commerce and Tax. Detailed explanation of the steps as applied for these intersections and the results of calculations are given.

For these intersections, SPF values for multiple-vehicle crashes is calculated and then multiplied by the appropriate CMFs to adjust base conditions to site exact geometric characteristics and traffic control features and afterward, the result obtained were multiplied by the proper calibration factor. The value for each individual CMF has been found, all of the CMFs are multiplied together which indicates the combined CMF value. Calibration factor for the 22 signalized intersections were computed as shown in Table 5. Calculations were conducted for each intersection separately as shown in Table 5. The summation of the observed crash frequencies is divided by the summation of the predicted average crash frequencies to find the calibration factor, Ci, equal to 1.10.

Table 5: computation of calibration factor

Name of Intersection	AADT major	AADT minor	CMF 1	CMF 2	CMF 3	CMF 4	CMF 5	CMF 6	Years of data	Predicted Crashes	Observed Crashes
Binavi 1	38672	17361	0.86	0.8836	0.92	1	1	1	5	27.005	38
Binavi 2	12424	7855	0.66	0.78	0.85	1	1	1	5	6.34885	17
Chinar	3436	3436	0.66	0.78	0.85	1	0.9107	1	5	1.334	4
Chira	45304	12297	0.86	0.8836	0.92	1	0.9107	1	5	29.287	15
Commerce	33433	2856	0.86	0.8836	0.92	1	1	1	5	13.245	33
Daristan	13125	11532	0.66	0.78	0.85	1	0.9107	1	5	7.3623	9
Diyary	36975	1454	0.86	0.8836	0.92	1	0.9107	1	5	13.41	15
Dohuk Stadium	21895	15980	0.66	0.78	0.85	1	0.9107	1	5	13.73	19
Emergency	52225	15887	0.86	0.8836	0.92	1	0.9107	1	5	36.64	11
Etite	28688	9636	0.86	0.8836	0.92	1	1	1	5	18.205	44
Malta	36528	10571	0.66	0.78	0.85	1	0.9107	1	5	21.519	15
Masik 2	1710	1388	0.66	0.78	0.85	1	0.9107	1	5	0.51	6
Melhem Mosque	15809	7763	0.66	0.78	0.85	1	0.9107	1	5	8.203	9
Newroz	26808	16338	0.86	0.8836	0.92	1	0.9107	1	5	17.6	22
Qazi Mohammad Mosque	57327	13403	0.66	0.78	0.85	1	0.9107	1	5	5.816	9
Shahidan	29191	9225	0.86	0.8836	0.92	1	0.9107	1	5	5.272	22
Shorash	24049	10704	0.86	0.8836	0.92	1	0.9107	1	5	13.98	5
Sulav	23863	23201	0.93	0.94	0.96	1	0.9107	1	5	20.34	4
Tax	32812	24940	0.66	0.78	0.85	1	1	1	5	23.52	44
Zari land	31462	21732	0.66	0.78	0.85	1	0.9107	1	5	21.71	29
Zirka 1	50502	20692	0.86	0.8836	0.92	1	0.9107	1	5	37.815	5
Zirka 2	15084	9409	0.86	0.8836	0.92	1	0.9107	1	5	8.0567	13
									Total	350.91	388
Calibration Factor	1.105700241										

- CMF1: Intersection Left-Turn Lanes, CMF2: Intersection Left-Turn Signal Phasing, CMF3, Intersection Right-Turn Lanes

  CMF4: Right Turn on Red, CMF5: Lighting, CMF6: Red Light Cameras
- Not all the treatments have available CMFs, however, a trend about the possible change in crashes or user performance is identified (Refer to Table 8)

SPF values for multiple-vehicle crashes is calculated from (11) and Table 6. Summary of crash modification factors and predicted average crash frequency for all high crash intersections are also shown in Table 6.

Table 6: summary of crash modification factors and predicted average crash frequency for high crash intersections

		SPF Coefficients										
Intersection	**Geometry**	**A**	**B**	**C**	**Initial Predicted Crashes (SPF)**	**CMF 1 (Intersection Left-turn Lane)**	**CMF 2 (Intersection Left-Turn Lane signal phasing)**	**CMF 3 (Intersection Right-Turn Lane)**	**CMF 4 (Right-turn on red)**	**CMF 5 (Lighting)**	**CMF 6 (Red Light Camera)**	**Predicted Crashes for/year**
Binavi 1	T-intersection	-12.13	1.11	0.26	8.43	0.86	0.884	0.92	1	0.9107	1	5.98
Binavi 2	Cross-intersection	-10.99	1.07	0.23	3.190	0.66	0.78	0.85	1	0.9107	1	1.41
Commerce	T-intersection	-12.13	1.11	0.26	4.491	0.86	0.884	0.92	1	0.9107	1	3.17
Etite	T-intersection	-12.13	1.11	0.26	5.198	0.86	0.884	0.92	1	1	1	4.02
Tax	Cross-intersection	-10.99	1.07	0.23	11.76	0.66	0.78	0.85	1	0.9107	1	5.19

CMFs that were used to estimate the possible modification in expected crash frequency or crash plus or minus a standard error as a result of implementing a specific treatment at each intersection and the expected average crash frequency after application of different treatments are given in Table 7 and the summary of possible treatments for high crash signalized intersections and percent of reduction in crashes is shown in Table 8. The table shows that not all the treatments have available CMFs, however, a trend about the possible change in crashes or human performance is identified. Furthermore, it can be noticed that there is a significant effect on the expected average crash frequency after all treatments executed at intersections.

Table 7: predicted average crash frequency with treatment-high crash intersections

				Predicted Crashes with Treatments Intersections				
Treatment category	Treatments	CM Fs	Std. Error	Etite	Binavi 1	Binavi 2	Commerce	Tax
Intersection Type	Convert at grade intersection to grade separated interchange	0.73	0.08	2.2 to 3.5	3.3 to 5.3	-	-	2.9 to 4.6
	Convert signalized intersection to a modern roundabout.	0.99	0.1	3.1 to 4.7	7.0 to 4.7	1.6 to 1.1	2.5 to 3.7	4.1 to 6.1
Intersection Design Elements	Provide intersection lighting	0.62	0.1	1.6 to 3.2	-	-	-	-
Intersection Traffic Control and Operational Elements	Install red-light cameras (Angle crashes)	0.74	0.03	0.62 to 0.732	-	0.26 to 0.31	-	-

Table 8: summary of possible treatments for high crash signalized intersections in duhok city and % of reduction in crashes

	Treatments for High Crash Signalized Intersections in Duhok City	Reduction in Crashes after Treatment				
		Etite	Binavi 1	Binavi 2	Commerce	Tax
1	Convert at grade intersection to grade separated interchange	**12-45 %**	**11-45%**	-	-	**11-44%**
2	Convert signalized intersection to a modern roundabout.	**23%**	**21%**	**22%**	**21%**	**21%**
3	Provide intersection lighting	**20 - 60 %**	-	-	-	-
4	Install red-light cameras (Angle crashes)	**20 - 33 %**	-	**20-33%**	-	-
5	Modifying change plus clearance interval	-	-	**44%**	-	-
6	Provide actuated control	Reduces some types of crashes compared to pre-timed traffic signals				
7	Operate signals in "night-flash" mode	Reduces nighttime and nighttime right-angle crashes **(Tax intersection is critical)**				
8	Provide advance static warning signs and beacons	Appears to reduce crashes **(Etite intersection is critical)**				
9	Provide advance overhead guide signs	Reduces crash occurrences **(Etite intersection is critical)**				
10	Install rumble strips on intersection approaches	Reduce all crashes of all severities				
11	Close or relocate access points in intersection functional area	Reduces rear-end crashes and angle crashes				
12	Provide corner clearance	Reduce all crashes of all severities				

4 CONCLUSION

Due to the common occurrence of angle, rear-end and side swipe crashes in Duhok city, and the dangerous consequences associated with them, a study was undertaken into the nature of, and possible countermeasures that might reduce these crashes. The approach used in this study involved filtering crash data using traffic directorate crash database and field survey to ensure required data such as geometric characteristics to check the possibility of applying different countermeasures and traffic volume are collected for descriptive study, different mathematical methods for identifying high crash locations and application of HSM predictive method to identify possible countermeasures. The HCLs improvement can be an effective engineering approach to alleviate the safety problems at critical locations. Distribution of crashes by type indicates that the rear end, angle, and side swipe are common type of crashes in which rear-end crashes account for 36.8%, angle crashes represent 36.4% and side swipe crashes constitute 12% of total crashes.

Identification methodology of high crash locations is necessary to determine the sites causing the occurrence of the higher risk on the roads. Using the mathematical methods, the results indicated that Ranking of the intersections by crash frequency method showed that Tax intersection has the highest rank according to angle crashes, while both Commerce and Etite intersections have the highest rank according to rear-end and side swipe crashes. Ranking of the intersections depending on their angle crash rates indicates that the Benavi 2 intersection has the highest rank, the second rank is related to Etite intersection and the third rank is related to Tax intersection. For rear-end and side swipe crashes, Masik2 has the highest rank followed by Commerce intersection and the third rank is related to Etite intersection. The intersections considered for further review by angle critical crash rate are Binavi1, Binavi 2 and Etite intersections. According to rear-end and side swipe critical crash rate method, Binavi 1, Commerce, and Tax are high crash locations.

There are a number of countermeasures to reduce multi-vehicle crashes involving treatments related to intersection types, treatments related to intersection design elements, treatments related to intersection traffic control and operational fundamentals and treatments related to access management. The results indicated that one approach/countermeasure to crash prevention may work effectively, however, a combination of approaches and/or countermeasures will give greater impact. Generally, converting at grade intersection to grade separated interchange will reduce traffic congestion, reduce vehicle conflicts and would provide major reductions in angle and rear end collisions. Converting signalized intersection to a modern roundabout will decrease traffic speed. The reduction in speed and conflict points contributes to the crash reductions when comparing to signalized intersections. Rumble strips on intersection approaches can been used in the course of traffic calming or speed management plans, in intersections. Installing red-light cameras at intersections will record the occurrence of red-light violations and thereby reduces the red-light runner that will reduce right-angle crashes. Modify yellow and all-red interval that may reduce right angle and rear end crashes which are related to change interval lengths that are possibly too short. Providing advance static warning signs and beacons and advance overhead guide signs will reduce crashes attributed to drivers' inattention as being unaware of the presence of the intersection. Closing or relocating access points in intersection functional area will reduce crash frequencies related to driveways adjacent to the intersection. Improving visibility of the intersection by improving lighting will reduce night time crashes when drivers are unaware of the presence of the intersections.

One of the important extensions to this research is investigating the possible effect of improvement of pavement condition parameters and intersection geometric characteristics. Driver-based countermeasures are required and comprise educational programs, guiding enforcement, and graduated driver licensing to improve intersection safety and reduce crash risk. Including severity levels, such as fatality or serious injury to identify HCLs using the cost of crashes.

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