

Serious Conflicts: A Safety Performance Measure at Signalized Intersections



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Abstract There is a challenge to identify potential sites for safety improvement in case of shortage in crash data. This study explores alternative method based on traffic conflicts as a surrogate safety measure instead of crash data. The study demonstrates two family major safety assessment streams; three of crash-based methods proposed by Highway Safety Manual and two conflict-based methods. For crash-based methods, Empirical Bayes (EB-method), crash frequency and crash rate measures are used. Conflicts frequency and conflicts rate for two surrogate safety indicators are used in the conflict-based methods, in this study, EB-method is used as a benchmark for comparison. The safety evaluation was performed separately for 9 signalized intersections, the safety measures are estimated and compared through Pearson correlation analysis while hazard location identification results through the use of rank-based mean absolute. Results showed that the serious conflicts frequency as a conflict-based method had a high correlation and a coefficient of 0.986 with the EB-method in the resulting outcomes and performed better than crash frequency method in identifying hazard location when compared with EB-method. Therefore, the serious conflicts frequency can serve as a viable option for safety performance evaluation and hazard locations identification, especially when sufficient crash data are not obtainable.

Keywords Traffic conflicts · Serious conflicts · Hazard location · Safety

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1 Introduction

With the social costs of crashes being so large, it is important to minimize crashes as much as possible. Safety assessment tools are a key component in continuing to identify potential sites for safety improvement in many countries. There are several approaches to measure safety ranging from using crash data to crash prediction models which relate the expected crash frequency to traffic volume and geometric characteristics. Whereas the use of statistical models based on historical crash data are most common in traffic engineering today. There are availability and quality problems associated with the data on which they are based. However, this approach is also considered ‘reactive’ in nature rather than ‘proactive’, where a significant number of crashes must occur before the problem is identified and suitable corrective measures are implemented [1]. Understanding these problems, Leur and Sayed [2] proposed a framework for proactive safety planning, i.e. planning that is not entirely based on historical crash data but uses surrogate measures such as the use of safety indicators and predictive models.

Highway Safety Manual (HSM) is a major effort in developing a leading reference for safety analysts and engineers. Safety Performance Measures (SPMs) in HSM require modeling efforts and different data acquisition. HSM didn’t include surrogate safety measures within the proposed quantitative measures of safety in the first edition and reported that the reliability of these events in predicting expected crashes has not been fully proven [3].

Tarko et al. [4] reported that HSM should include not only standard but also emerging methods of safety evaluation in order to serve as a major resource for safety analysts. For example, the Highway Capacity Manual (HCM) in recent years has recognized micro-simulation as a substitutional approach to highway capacity analysis and has adopted this new methodology as an approach complementary to crash-based analyses. Similarly, the HSM may consider surrogate measures as a viable and complementary approach to safety assessment that may be used separately or jointly with crash data, provided these methods are deemed viable, accurate, and defensible.

Surrogate safety measures (SSM) are any events that can be correlated with crashes. The term “surrogate” represents that these measures do not rely on crash data and instead are meant to be an alternative or a complement to crash record-based analyses. Many factors through different techniques have been proposed for use as surrogate safety measures, such as volume, speed, delay, accepted gaps, headways and deceleration-to-safety time. A widely common surrogate measure for traffic safety is the Traffic Conflict Technique (TCT) [4–6]. TCT recognizes potential collision between two or more road users. The application of TCTs for analyzing traffic safety problems has seen considerable research interest, having gained acceptance as a proactive surrogate approach [7, 8]. However, the validity of using traffic conflicts as alternative to observed or expected average crash frequency (EACF) in HSM is difficult to investigate given the limited amount of data available for such purposes. In many countries, including Iraq, it is no

longer a policy to report crashes that do not result in injury. As a result, there is often very little data available, making location-specific safety indicator validation against crashes data very difficult task. Arguably, the idea of using crash data is against the principles of traffic safety policies.

The main purpose of this paper is to explore an alternative technique to measure safety by using a surrogate approach based on traffic conflicts to overcome the problem of the unavailability of crash data and provide an alternative way for safety assessments of four-leg signalized intersection at urban area. Also, the research is to support the validity of TCT as a surrogate measure alternative to crash-based measures.

2 Crash-Based Methods to Measure and Assess Safety

Crashes analysis is the most direct method of assessing traffic safety, but it has at least two limitations. First, the relative rarity and randomness of crashes make them difficult to study without a significant amount of historical crash data [9]. Second, not all crashes are reported, and the level of underreporting depends on the severity of the crashes and the type of road users involved [10, 11]. Further, traffic safety analyses are based on crash data implies an ‘after-the-fact’ or ‘reactive’ approach, whereby crashes must actually occur before preventive measures are taken.

In HSM, there are 13 quantitative performance measures for identifying the safety performance for sites or facilities. Each of the performance measures are described in HSM part B Sect. 4.2.3 along with the strengths and limitations. Applied performance measures in HSM require modeling efforts and different data acquisition from the traffic safety analyst which may not be available particularly in developing countries.

In the field of safety analyses dealing with different SPMs, several studies performed comparative analyses between outputs of different measures of safety (Crash Frequency (CF), Crash Rate (CR), EB-method, critical crash rate, equivalent property damage only, proportion method... etc.) in their seeking to explore which measures of safety better in identifications of sites with most probable profit from safety improvement [12–15]. Further, HSM recommended applying multiple performance measures to the same data set [3].

Oftentimes observed CF and CR are used as a tool to recognize and prioritize sites as in need of modifications and for appraisal of the effectiveness of treatments. However, based on requirements of AASHTO and FHWA, short time periods (less than three years) should not be used for analyzing and assessing safety at site due to effect Regression-to-the-Mean (RTM) bias [3, 16]. Observed CF is obtained by counting the number of crashes at an intersection or a roadway segment, over a certain period of time, while CR normalizes the number of crashes relative to exposure(traffic volume) by dividing the total number of crashes by Million Entering Vehicles (MEV) [3, 16].

In order to address some limitations of the CF and CR methods, many agencies develop and applied statistical models using regression analysis. These models address RTM bias and also provide the ability to reliably estimate of crash frequency for not only existing roadway conditions but also changes to a new design for the site prior to its construction and use. When historic crash data for a specific site or facility is combined with the results of the model estimation, the reliability of crash estimation is improved due to accounting RTM bias [17]. The EB-method in HSM combines an estimation of the observed crash data of the study site with characteristics of similar sites using safety performance functions (SPFs) to estimate the predicted number of crashes. In the HSM, the EB-method is used as part of the predictive method. Montella [13], Maskooni and Haghghi [18] reported that EB-method performs better than other direct SPMs and considered the most consistent and reliable method for identifying priority investigation locations. The weighted adjustment factor in EB-method is used to determine how much “weight” is given to the two estimate methods: the estimate derived using SPFs based on site (intersection or roadway segment) with similar feature and estimate of expected number of crashes on the site of interest. The overdispersion parameter (k) that coincides with SPF is used to determine the value of the weighted adjustment factor. Equation (1) shows how the site-specific expected number of crashes according to the EB-method is calculated, Eq. (2) is for obtaining weighting adjustment factor [3]:

$$N_{\text{expected}} = w \times N_{\text{predicted}} + (1.00 - w) \times N_{\text{observed}} \tag{1}$$

$$w = \frac{1}{1 + k \times \left[\sum_{\text{all study years}} N_{\text{predicted}} \right]} \tag{2}$$

Where N_{expected} is the estimate of EACF for the study period, $N_{\text{predicted}}$ is the predictive model estimate of crash frequency for the study period based on the SPF in HSM; N_{observed} is the observed crash frequency at the site over the study period, w is the weighted adjustment to be placed on the SPF prediction, and k is the overdispersion parameter from the associated SPF.

3 Conflict-Based Methods to Measure and Assess Safety

TCT is considered as most direct of the all indirect methods of road safety measurement as, it deals with observing and recording of the conflict events in real time. Further, Lareshyn and Várhelyi [19] stated that, if the goals are to make safety

diagnosis of a site, TCT is the right method for that. Tageldin and Sayed [20] pointed out that the basic principle behind using TCT in safety assessment is based on the hypothesis that all interactions between road users fall within a continuum of safety-related events, with crashes at the top of a pyramid of traffic events, followed by serious conflicts. The main idea behind studying traffic conflicts is that it is possible to draw inference on the incidence of the top of the safety hierarchy (crashes) by keeping a record of less severe, but more frequent events, at the bottom.

According to the operational definitions of the traffic conflict, it is possible to group them into two types: Evasive actions-based traffic conflict and temporal (and (or) spatial) proximity-based traffic conflict. Parker and Zegeer [21] defined evasive actions-based traffic conflict as "... an event involving two or more road users, in which the action of one user causes the other user to make an evasive maneuver to avoid a collision". Hence, a study of conflict according to that definition includes considerable judgment on conflict situation. Further, this definition infers that conflicts and crashes are of similar nature unless for the presence and the success of evasive action. In a proximity-based traffic conflict, the critical events are recognized depending on temporal (and (or) spatial) proximity. It is defined as "...an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged" [22]. The most common temporal proximity indicator family is Time to Collision (TTC) [23]. Specifically, a conflict was defined to be a serious (severe) conflict if the TTC value was less or equal than the threshold of 1.5 s. However, the threshold values vary in relevant studies from 1.0 to 5.0 s. For intersections, it is generally considered that a TTC, equal or less than 1.5 s., would result in a critical situation [6, 24].

3.1 Validity of Surrogate Measure

Some studies have supported the traffic conflict technique validity but others have failed [25]. The failure of some studies to support a relationship between conflicts and collisions was related to issues such as the accuracy of collision data. There are many ways to study the validity of surrogate safety measure-expert judgments, comparison with other "indirect" measures, comparison with observed/reported crashes, etc. A review of previous literatures in this area revealed that there are several approaches have been used for validation surrogate measure of safety, which can be divided into three main categories—product validations, relative product validity and process validation. Different degrees and types of validity might be acceptable in surrogate safety analysis [23, 26]. When the researchers use surrogate safety indicator to assess safety, they should notes, the usefulness of a SSM does, however, not (only) depend on the extent to which expected crash numbers can be correctly estimated (Grayson et al. [27]. The usefulness mainly

depends on whether safety problems can be detected or not, and/or road safety counter-measures/treatments can be compared or evaluated [28, 29].

Product and/or relative validity may allow identifying high-risk locations, to evaluate which road designs have a better safety performance than others, and which measures have a positive effect on the (expected) number of crashes that take place. The approaches suggested into investigate the validity of SSM can be classified as:

- Linear correlation between recorded crashes and numbers of observed critical events, e.g. [30, 31].
- Minimization of the variance of the ratio between critical events and crashes, e.g. [32, 33]
- Analysis of SPFs that estimate the predicted number of crashes from the number of critical events (and not flow) e.g. [24].
- Comparison of the estimated number of crashes based on critical events calculated from the simulation model with the crash-based methods, e.g. [6, 15]
- Comparison of the estimated number of crashes calculated using the extreme value theory methods with the estimated number of crashes (based on crash data), e.g. [34].
- Comparison between a critical incident-based and crash-based before and after study e.g. [35].

Process validity indicates the extent to which safety indicators (conflicts) can be used to characterize the process that leads to crashes [36]. In this approach not necessarily for indicator to tell us why or how some locations perform better or worse than other locations.

4 Objective of the Study

The main objective of the paper is to compare safety measure of conflict-based methods based on two surrogate safety indicators (evasive actions-based traffic conflict and temporal proximity-based traffic conflict) with safety performance measure of crash-based methods. Validation test is conducted to investigate the ability of the surrogate safety indicators of identifying the most probable site to profit from safety improvement.

5 Study Sites and Data Collection

A sample of 9 sites are studied in view of the research requirements according to the criteria of; all sites are signalized intersections and located in the urban area surrounding the CBD of Baghdad city, no major changes in geometric design and



Fig. 1 Map of selected sites

surrounding area of sites during the study period (2015–2017), and availability of crash data for the corresponding period. Figure 1 shows the locations and names of intersections in the study sites. Geometric data and traffic control needed in this study are collected from the field in each site, other data needed for this study as follows:

5.1 *Crash Data*

For purpose of this study, crash data are collected for three years from 2015 to 2017 for 9 intersections. According to crash data there are 143 crashes occurred in 9 sites during 3 years, the average crashes for intersections was 5.29 crashes per year. Crash data in this study are represented for the crashes between vehicles only.

5.2 *Traffic Volume and Conflict Data*

By the aid of positioning of surveillance cameras at each study site as well as field observation, necessary input data of traffic volume and conflicts was obtained. For each studied intersection, traffic volume and conflicts are observed for 16 h on workdays. The data collection is divided in each day into 4 h in a.m. period and 4 h

in p.m. period, these periods include (a morning peak, afternoon peak and off-peak at mid-morning and evening).

Two types of traffic volume measurements have been used: hourly traffic volume (HTV) and annual average daily traffic (AADT) for major and minor streets. The AADT is estimated from account peak hour volume (PHV) for each site by using conversion factor (K) in HCM for the urbanized area to convert PHV to AADT.

The AADT is calculated based on traffic survey in 2017, AADT for 2015 and 2016 which have been estimated based on used growth factor for traffic that has been obtained from the relevant authority of urban transportation study in Baghdad city.

Conflict data are collected with the help of video recording equipment. In this study, conflict data observed for 20 min per hour from 16 h of video recording, therefore, the total hour of conflicts observation used in this study is 5 h and 20 min for each intersection. These period fulfills requirements reported by Glauz and Migletz [37] that the minimum number of hours needed to estimate mean hourly count for major conflict data for signalized intersection should not less than 3 h and 25 min as a period of observation per each site.

Two categorizes of conflict measures are collected; total traffic conflicts frequency based on evasive actions and serious conflicts frequency based on temporal proximity. Traffic conflicts frequency is identified based on definition introduced by Parker and Zegeer [21]. These conflicts can be identified by careful observation of traffic flow at an intersection. When the action of a vehicle (first vehicle) places another vehicle (second vehicle) on a collision path unless the second vehicle takes evasive action to avoid a crash, the evasive action of the second vehicle can be identified by one or more of the following: brake-light indication, front lounging of the vehicle or squealing of tires, and swerve of a vehicle.

Based on a sample of 1200 conflicts situation collected from the field, analysis of local data revealed that the value of threshold 1.5 s. for TTC to distinguish serious conflicts is close to local field data. Therefore, in this study, serious conflict frequency is identified based on the definitions introduced by Amundsen and Hyden [22] using 1.5 s as threshold values for TTC according to the conflict situations (rear-end, crossing or head on conflicts) and based on distance and speed for vehicles involving in a conflict situation.

Further, Hourly Traffic Conflict (HTC) is used to represent the number of total conflicts frequency based on evasive actions at a site divided by observation hours. On the other hand, Hourly Serious Conflict (HSC) represents the number of serious conflicts frequency (temporal proximity-based traffic conflict with $TTC \leq 1.5$ s) at a site divided by observation hours. Observed conflict data in this study represent the conflicts between vehicles only.

6 Methodology

To assess the performance of the conflict-based methods in identifying and prioritizing sites for potential safety improvement, all intersections in the study data were prioritized by results from the conflict-based methods compared with the prioritized results based on three crash-based methods (EB-method, crash frequency and crash rate). In addition to assess the performance of the observed crash frequency and crash rate methods corresponding to the EB-method performance, which is the benchmark for correct identification in this study.

Further, the EACF according to the EB-method is obtained based on procedure of HSM predictive method for four-leg Signalized Intersection (4SG) in the urban area (The details steps, functions, tables and figure used in a predictive method for intersections is described in HSM, part C, Chap. 12, Sect. 12.6.2).

7 Statistical Tests Used in the Validation

- 1 Test correlation between incidents, the value of the pearson correlation coefficient (r) between two set of incidents are used in comparison and validation. A higher correlation coefficient indicated a stronger relationship between two sets of outputs. Statistics are calculated based on the following equations [38, 39]:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n \sum x^2 - (\sum x)^2][n \sum y^2 - (\sum y)^2]}} \tag{3}$$

$$t = \frac{r}{\sqrt{\frac{1-r^2}{n-2}}} \tag{4}$$

Where r is the Pearson correlation coefficient, n is the number of sample, x, y is the data of two compared sets of incidents; t is the t-statistic.

The value of t-statistic (based on Eq. [4]) can be compared to a critical t-value at 95% level of significance to define the significant or insignificant correlation between two sets on incidents.

- 2 Comparative analysis based on rank positions, in this test, the rank position of intersections based on two sets of incidents are used in comparison and validation. *Test based on rank positions consists of two steps:*

Step A: Ranking intersection based on incidents (crashes or/and conflicts). In this step, each intersection will be ranked based on their incidents as following:

- Ranking intersections based on outputs of crash-based measures.
 Each intersection will be ranked based on the crash frequency for the 3-year study period for CF method, crash/MEV for CR and EACF/year for EB-method. In the process of screening sites for further details of evaluation to identify proposed improvements and countermeasure, ranking is achieved from highest to lowest values represented by studied safety performance measures (EB-method,CF and CR). In this study, it is intended to conduct a comparison between the output of simple ranking according to the value of safety measure associated in each site based on SPMs used. Table 1 shows that site No.5 is ranked 1 due to EB (7.669 crash/year) and CF (21crash for three years) while site No. 6 is ranked 1 due to CR (0.304 crashes/MEV). Although there is similarity in ranking of site No.5 (14th Ramadhan intersection) and site No.2 (Al-Saylow intersection) due to CF and EB-method, there is no such similarity for other sites and further statistical analysis and priority optimization are appreciated.
- Ranking intersections based on conflict-based measures.
 For two surrogate safety indicators used in this study, each intersection will be ranked based on:
 - i. Average hourly conflicts frequency (for HTC and HSC)
 - ii. Hourly conflict rate (Hourly conflicts rate represented the average hourly conflicts frequency divided by hourly volume and that denoted by HSCR for traffic conflicts identified based on evasive actions and HSCR for traffic conflicts identified based on temporal proximity with $TTC \leq 1.5$ s.).

Table 2 summarizes the output of indirect safety measures and simple ranks of intersections according to the conflicts-based measures (evasive actions-based traffic conflict and temporal proximity-based traffic conflict). Ranking sites for conflict-based measures is performed from highest to lowest values. Table 2 shows that, the site No. 5 is ranked 1 due to HTC (246) and HSC (13.5), while site

Table 1 Crash-based measures and ranking of sites

Site no	Intersection name	Direct SPMs			Simple ranking ^b		
		EB ^a	CF	CR	EB	CF	CR
1	Al-Muthanna	6.878	17	0.183	2	3	7
2	Al-Saylow	5.144	12	0.156	9	9	8
3	Al Sakraha	5.760	13	0.134	6	8	9
4	Beirut Square	6.377	16	0.185	4	5	6
5	14th Ramadhan	7.669	21	0.221	1	1	4
6	Aqaba ban Nafaa	5.698	17	0.304	7	3	1
7	Al-Masbah	6.481	18	0.266	3	2	2
8	Al-Sharika	6.060	15	0.235	5	6	3
9	Al-Jadyriah	5.335	14	0.196	8	7	5

^aEB: EACF per year due to Eq. [1]

^bSites are ranked using the highest value of safety performance measure

Table 2 Conflict-based measures and ranking of sites

Site no.	Intersection name	Indirect SPMs				Simple ranking ^a			
		HTC	HTCR	HSC	HSCR	HTC	HTCR	HSC	HSCR
1	Al-Muthanna	216	36.01	11.5	1,916	3	6	2	4
2	Al-Saylow	167	32.95	7.5	1,474	9	9	9	9
3	Al Sakraha	197	34.12	9.5	1,645	6	8	5	8
4	Beirut Square	213	36.81	11	1,899	4	5	3	5
5	14th Ramadhan	246	34.31	13.5	1,883	1	7	1	6
6	Aqaba ban Nafaa	180	44.70	9	2,235	8	2	7	1
7	Al-Masbah	220	45.57	10.5	2,176	2	1	4	2
8	Al-Sharika	195	39.66	9.5	1,929	7	3	5	3
9	Al-Jadyriah	200	10.12	8.5	1,648	5	8	8	7

^aSites are ranked using the highest value of conflict-based measures

No. 6 and site No. 7 are ranked 1 due to HSCR and HTCR respectively and further statistical analysis and priority optimization are appreciated.

Step B: Ranking Comparison.

Several studies performed a comparative analysis between two SPMs based on rank-based MAE [13–15]. In this test, the intersections rankings according to crash-based measures will be compared to the intersections rankings according to conflicts-based measures. The rank-based mean absolute error (rank-base MAE) was used to compare the ranks derived from the two methods. The intersections identified by the methods were sorted in accordance with the outputs of the methods. The derived ranks from the outputs were then compared through the use of the MAE. The MAE quantified how close one set of ranks (e.g., the ranks in the subject SPM) to the other set of ranks (e.g., the ranks for reference SPM), the lower value indicated that the two sets had a less relative error. The comparative between rank positions of two sets of data is achieved according to the Eq. (5).

$$MAE(rank) = \frac{1}{n} \sum |rank(x) - rank(y)| \tag{5}$$

Where: *n* is the number of locations, Rank (*x*) is the rank of location on the basis of reference SPM and Rank (*y*) is the rank of location on the basis of the other performance measures that will compared.

8 Test Results and Discussion

Test the predictive safety performance capability for CF and CR methods using the EB-method as a benchmark for crash-based methods by comparing of the value of measures safety and ranking of intersections based on CF and CR methods as

Table 3 Correlation coefficients and MAE values for study sites

Statistic	Intersection comparison		
	Reference SPM	Direct subject SPM	
	EB	CF	CR
r	1	0.882	0.178
t-statistic(r)		4.951^a	0.478
Rank-based MAE		1.222	2.888

^aSignificant at 95% confidence interval level

subject SPMs versus the value of measures safety and ranking of intersections based EB-method as reference SPM, the result revealed that the higher correlation coefficient and lowest MAE is obtained by CF method. The correlation coefficient value between EB-method and CF is 0.882, which is significant at a 95% level of confidence. It is worth noticing that, the CR performance measure presented the insignificant correlation coefficient and higher MAE with EB-method, this is probably due to the influence of traffic volume when comparing study sites. Table 3 presents the results of comparative analysis for crash-based methods.

The CR method assumed a linear relationship between traffic volume and crash frequency, based on results, is clear the effect of traffic volume of biasing in results of identifying prioritizing of sites, since the CR method identified the sites with the lowest volume at the highest rank (site No 6,7, and 8). Further, the rank order of sites based on the CR method completely different to EB-method, it is near to the ranking sites based on traffic volume (from the lowest value to higher value).

These findings support the fact, that the crash rate method is biased towards low-volume sites. This result is quite alarming, as many agencies still use this method in the analysis of crashes.

From a practical point of view, an important result is that the CF method performed better than CR method in relation to EB-method. This result is matching with other studies of; Persaud et al. [12], Montella [13], Lim and Kweon [14].

Table 4 presents the results of a comparative analysis between crash-based measures (represented by EB-method, CF and CR) and conflicts-based measures ((represented by conflicts frequency (HTC and HSC) and conflict rate (HTCR and HSCR)) according to their predictive safety performance at intersections. The results revealed the following:

- Assuming that EB-method as the benchmark in comparison with two measures of safety for each indicator of conflicts, the result showed that HSC has highest correlation coefficient and lowest MAE with EB-method, the correlation coefficient value of HSC was 0.986, which is significant at a 95% level of confidence. Also, HTC has a high correlation coefficient with EB-method and significant at a 95% level of confidence.
- A comparison analyses by assuming the CF as the benchmark in comparison with measures of safety for each indicator of conflicts, showed that predictive

Table 4 Correlation coefficients and MAE values for study sites

Statistic	Intersection comparison				
	Reference direct SPM	Indirect-subject SPM			
		HTC	HTCR	HSC	HSCR
<i>r</i>	EB	0.912	-0.07	0.986	0.419
t-statistic(<i>r</i>)		5.88*	-0.19	15.64*	1.22
Rank-based MAE		0.888	2.88	0.33	2.22
<i>r</i>	CF	0.807	0.30	0.86	0.632
t-statistic(<i>r</i>)		3.62*	0.84	4.46*	2.16
Rank-based MAE		1.222	1.88	1.33	1.222
<i>r</i>	CR	0.087	0.87	0.11	0.87
t-statistic(<i>r</i>)		0.23	4.69*	0.31	4.76*
Rank-based MAE		2.666	1.11	3.22	1.11

*Significant at 95% confidence interval level

safety performance capabilities of conflicts frequency for two indicators of conflicts (HTC and HSC) also have significant correlation coefficient.

- Performance of conflict rate (for each of HTCR and HSCR) with EB-method and CF was similar to the performance of CR with EB-method, the correlation coefficient for HTCR and HSCR with each of EB-method and CF were insignificant.
- Assuming the CR method as the benchmark in comparison showed significant correlation coefficient with HTCR and HSCR only, while other conflicts measures revealed insignificant correlation coefficient at a 95% level of confidence with CR method.

Safety performance measures are calculated for 9 signalized intersections in the study area, and ranks are derived on the basis of the calculated performance measures, the results above showed that conflicts frequency of two surrogate safety indicators (HTC and HSC) are more closely related to the EACF estimated based on the EB-method (correlation coefficients of 0.912 and 0.986 respectively) than CF (correlation coefficients of 0.807 and 0.860 respectively), and the MAE values support these comparison results, too. Hence, it can be concluded that the performance of conflicts frequency as a conflict-method is fairly similar to the EB-method which is considered as the most consistent and reliable method for identifying priority investigation locations and perform better than other direct SPMs according to several studies.

Further, when compared the coefficient of correlation and MAE value between EB-method and conflicts frequency (for each indicators) with coefficient of correlation and MAE value between EB-method and CF, the result suggest that conflicts frequency perform better than CF. The significant correlation coefficient between conflict rate for two indicators (HTCR and HSCR) and crash rate indicated that the

performance of the conflict rate also biased towards low-volume sites when compared with the EB-method.

Based on these findings, it appears that safety deficiencies at intersections can be pinpointed using the traffic conflicts frequency. However, this study is limited to the signalized intersection with AADT range from 52000 to 91000 veh./day according to the study sites.

9 Conclusions and Recommendations

This study explored the potential use of conflict-based methods as an alternative way of measuring safety performance when identifying sites with probable profit from safety improvement. The EB-method was used as a benchmark for conflict-based methods and crash-based methods, and the observed crash frequency and crash rate method were used as a comparison supplement. Generally, it was found that serious conflict frequency (HSC) had the highest relationship to the EACF based on EB-method and lowest MAE than other crash-based methods and conflict-based methods, that is mean that the serious conflict frequency method is better correlated with outputs of EB-method than with the CF in terms of the safety performance measures and identification high-risk locations.

In present study, based on nine intersections and 3 years of crash data, site No.5 (14th Ramadhan intersection) marked as hotspot and represented the site that probable profit from safety improvements, since it has the highest rankings (it is fall in rank No.1) based on the values of safety measures for EB-method, CF, HSC and HTC.

Further, the result showed that the crash rate method performed poorly in compared with the EB-method and has a higher relative error in terms of MAE; this result is consistent with the results of previous studies like the study conducted by [12–14]. The crash rate is intended to address one of the inherent limitations of the crash frequency method: failure to account for traffic volume differences across locations. However, the poor performance of the crash rate method in this the study showed that simply dividing the crash frequency by the traffic volume does not correctly account for the volume difference across locations from a safety evaluation viewpoint and leads to erroneous identification results. The crash frequency method performed better than the crash rate method in terms of MAE with EB-method. Performance of HSCR and HSCF as conflict-based methods comes similar to perform crash rate in identifying high-risk locations. However, many highway agencies still rely on crash rate to identify locations for potential safety improvements.

The results of this study have indicated the practical value of the TCT as a quantitative method for identifying safety problems at intersections. On-site- traffic conflicts observation demonstrated useful to understand the practical performing of the different intersections and the effect of other important factors on road traffic safety. With respect to the consistency of the conflicts data (conflicts frequency and severity) and the crash-based method for crash data of the period 2015–2017 it can

be stated that there was a reasonable level of agreement for two methods used in this study.

The techniques mentioned in this research are tools that support the effective decision. However, more studies with more sample size required to explore the relationship between the outputs of risk in the site depending on non-crash events should be carried to explain findings and develop solutions to the problems in the future.

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