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Procedia Computer Science 32 (2014) 364 – 371

Procedia Computer Science

5th International Conference on Ambient Systems, Networks and Technologies (ANT-2014)

The Development of Conflict Index for the Safety Assessment of Intersections Considering Crash Probability and Severity

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Abstract

The use of crash data based methodologies for safety evaluation has been usually problematic due to the many shortcomings such as, unavailability and low quality of historical crash data. Other than crash data based analysis, development of micro-simulation models in conjunction with surrogate safety measures is shown to have potential to complement traditional safety analysis. However several previous works found that existing measures for the assessment of intersection safety such as post-encroachment time (PET), time to collision (TTC) and speed cannot each one alone represent the overall safety levels including crash probability and severity simultaneously. Thus, this study aims to propose a safety measure that considers crash probability as well as expected severity. By utilizing the change in the total kinetic energy before and after the collision, angle of collision and PET, the proposed conflict index is derived. Several videotaped signalized intersections in Nagoya City, Japan are utilized to extract vehicle trajectories through which conflict characteristics are estimated. The relationship between the estimated distributions of the proposed index and the records of severe crashes of the same sites are presented. It is concluded that the proposed safety measure is successful in providing a similar ranking of different signalized intersection to the ranking which is based on the number of crashes occurred at each site. The proposed measure can assess policy makers in prioritizing different sites for safety improvements projects.

Keywords: *Safety assessment, Conflict index, Traffic conflict technique, Kinetic energy, Post-encroachment time*

1. Introduction

Despite the large amount of safety modelling research, absolute numbers of crashes and crash rates are still difficult to predict accurately. This has led to increase interest in traffic conflict technique and related surrogate

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doi:10.1016/j.procs.2014.05.436

measures as an approach to assess the safety of traffic facilities. Traffic conflict technique is a procedure which was defined the first time by Perkins et al.[1] through identifying traffic conflict patterns for over 20 corresponding crash patterns at intersections. Although several studies (Migletz et al. [2] and Lu et al.[3]) have found that traffic conflicts are good surrogates to crashes, direct correlation between the characteristics of traffic conflicts and accident frequency or severity is still not proven.

Several indices are proposed to measure traffic conflicts such as the post-encroachment time (PET) and the time to collision (TTC). These indices certainly indicate the probability of a collision to occur, but it cannot be directly linked to its severity. Thus, other indices are utilized to investigate the conflicts' severity such as speed. In general, a single reliable index that can present the overall safety performance including crash frequency and severity is still missing. Therefore, this study aims to propose a safety measure, Conflict Index CI, which can present the probability of a collision to occur and its expected severity as well, without the need to observe actual crashes. Furthermore, this study provides a comprehensive comparison with some relevant existing measures.

After introduction and literature review, empirical analysis on the reliability of existing safety measures in reflecting the safety levels of intersections is presented. Then the assumption and the development of the proposed safety measure and its derivation are discussed. A comparison between crash records at several signalized intersection in Nagoya City and empirically estimated crash indices at each site is presented to investigate the reliability of the proposed index. Finally, the paper ends up with summary of the results, conclusion and future works.

2. Literature Review

The frequency or rate of reported crashes is commonly used for the evaluation of safety at intersections. When following such approach, comprehensive historical crash data is necessary comprising at least several years. Highway Safety Manual[4] summarizes decades of traffic crash studies and proposes crash frequency/rate predictive methods considering geometric characteristics of traffic facilities and traffic conditions. These methods are subjected to many limitations in applicability and considered influencing factors. Thus, this approach is suitable for long term a posterior assessments. Here comes traffic conflict technique (TCT), in which surrogate indices are usually the measures for safety or risk, as an applicable alternative method that does not need long term measurements as compared to the crash data analysis.

Various conflict indicators have been suggested for the safety evaluation of traffic facilities. In general, Gettman and Head[5], Allen et al.[6], Tang and Nakamura[7] found that time to collision TTC and post-encroachment time PET are ranked as the best measures for the analysis of safety at intersections in the consideration of ease of measurement, and application to conflict types.

TTC is the best measure applying to rear-end conflicting events, while PET is the best measure applying to the angle conflicting events. Moreover, Tang and Nakamura[7] proposed the PET as a measure for safety performance during intergreen intervals. A PET during a change of phases is defined as the elapsed time from when the last clearing vehicle in the previous phase passes the conflict point till when the first entering vehicle of the subsequent phase arrives there. In their study, PET is used to estimate the number of conflicts. Conflicts are defined as encroachments between two vehicles with a PET of less than t sec. However, the PET alone cannot assess the safety of angle collisions, for example the impulse of the vehicles involved in the conflict is not considered, although it is a very important factor in determining the probability of a collision to occur. Therefore other indices have been used to evaluate the severity of a potential conflict such as the speed distribution of conflicting vehicles, conflict angle and acceleration distribution as summarized by Gettman and Head[5].

Several previous studies found that vehicle speed when a crash occurs (crash speed) significantly contributes to the severity of that crash (Kloeden et al.[8], Wang and Abdel-Aty[9], Pesanen[10], Kruysse[11] and Alhajyaseen et al. [12]). Kloeden et al. [8] concluded that the risk of involvement in a casualty crash increases more than exponentially with increasing free travelling speed above the mean traffic speed in rural roads. Moreover, Pesanen[10] found that a collision speed of 50 km per hour of a vehicle to pedestrians will lead to the risk of pedestrian fatal injury almost eight times higher as compared to a speed of 30 km per hour.

According to the Accident statistics[13] in 2011 of Japan National Police Agency, a significant (95% confidence level) exponential relationship was found between vehicle speeds when facing hazardous conditions and percentage

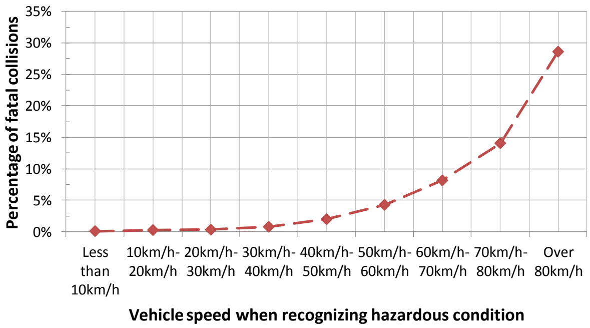


Fig. 1 Relationship between vehicle speeds when facing hazardous conditions and percentage of fatal collisions from total number of collisions in ordinary roads in Japan in 2011

of fatal collisions from total number of collisions in ordinary roads as shown in Fig. 1. This clearly shows that higher speeds at conflict points may contribute to higher conflict severities. Therefore it is reasonable to use the speeds of conflicting vehicles at the conflict point as an indicator for the severity of the conflict, assuming that these speeds would be very close to the crash speed if the conflict becomes a real crash. Sobhani et al.[14] developed a comprehensive simulation based approach for the safety assessment of road locations. The proposed methodology contains two main parts. Firstly, the estimation of number and severity level of conflicts using an existing micro-simulation model. The second part is the measurement of potential injury severity of each simulated conflict by modelling the relationship between driver behaviour and vehicle speed at the time of the rash and crash injury level using the Australian Crash In depth Study (ANCIS) database (Logan et al.[15]). However, the proposed methodology evaluates crash probability and potential severity separately. Furthermore, the amount and characteristics of crash data used in model development is not presented.

3. Methodology

This paper proposes a methodology to assess the safety performance without the need to have crash data and their detailed characteristics. It only needs empirical or simulated conflict data. In this study, the term conflict is defined as the condition where two consecutive vehicles pass a common point along their paths with a time difference of less than 5 seconds. Assuming vehicles' approaching speed as 50 km/hr, which is the most common speed limit in urban streets in Nagoya City, the distance that the vehicles can cruise in 5 seconds, is approximately 70m which indicates that any two consecutive vehicles with a time difference of more than 5 seconds are not likely to exist simultaneously inside the intersection. Thus, in this study a conflict is only observed if the time difference between the arrivals of the two consecutive vehicles is equal or less than 5 second.

4. Data Collection and Processing

In the first part of this paper, the relationships between numbers of sever crashes and empirically estimated speeds at conflicts points and PETs are investigated. For that, previously collected video data at five signalized intersection in Nagoya City, Japan were utilized (Table 1). Since this study utilizes empirical data from Japan, the analysis and definitions are based on left-hand traffic system where vehicles drive on the left-side of the road. All the observed intersections are operated by 4-phase plan where shared through-left turning phase is followed by exclusive right turning phase (left-hand traffic). The analyzed conflict is the one between the last clearing right-turning vehicle and the first entering through vehicle of the following signal phase (during the intergreen time). The analyzed sites are characterized with high through traffic demand. Thus, the occurrence of this type of conflict mainly depends on the presence of turning vehicle at the end of the exclusive right turning phase which is functions of the demand and arrival pattern of right-turners.

Table 1 presents the characteristics of the surveyed sites including geometry, traffic and survey date. Crash records for each intersection are obtained from Aichi Police Department for 6 years from January 2004 to December

Table 1 - Surveyed sites for the comparison analysis and related crash data

Intersection name	Analyzed conflicting streams [a)] Right Turning	Analyzed conflicting streams [a)] Through	Video Survey date	Intersection size W-E×N-S [a)]	Turning angle (deg.)	Right turning vehicle demand veh/hr	Number of reported crashes 2004 - 2010 [b)]
Hiroji-dori 1	W	S	24/2/2010 7:00-10:00	39×50	88	-	**2**
	S	E			95	-	
	N	W			95	-	
Sunadabashi	W	S	6/27/2008 7:30-11:00	53×30	90	140	**9**
	N	W			91	400	
Taiko-dori_3	E	N	10/13/2009 7:30-10:30	76×57	85	-	**10**
	W	S			84	76	
	N	W			95	76	
Atsutajingu-minami	E	N	21/07/2009 7:00-12:00	50×50	119	-	**13**
	W	S			119	-	
	S	E			61	-	
	N	W			61	84	
Suemori-dori 2	E	N	11/18/2008 9:00-12:00	58×60	112	-	**9**
	W	S			88	112	
	S	E			93	240	
	N	W			67	136	

[a)] Where N is north, S is south, W is west and E is east.

[b)] Crashes between clearing right turning vehicles and entering through traffic only.

Table 2 – Characteristics of observed conflicts including PET and summation of conflicting vehicle speeds

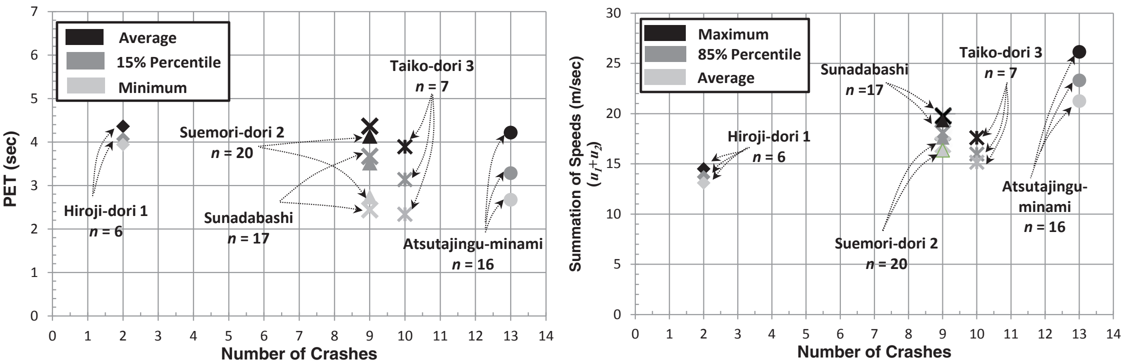
Intersection name		**Hiroji-dori 1**	**Sunadabashi**	**Taiko-dori_3**	**Atsutajingu-minami**	**Suemori-dori 2**
No. of Observed Conflicts (PET≤5 sec)		6	17	7	16	20
Summation of speeds of the conflicting vehicles (m/sec) [a)]	Max	14.51	19.80	17.59	26.14	19.31
	85% percentile	13.69	18.10	15.97	23.31	17.58
	Average	13.10	16.90	15.15	21.24	16.35
PET (sec) [b)]	Average	4.36	4.14	3.89	4.21	4.36
	15% Percentile	4.07	3.52	3.14	3.29	3.67
	Min	3.94	2.74	2.31	2.67	2.44

[a)] The summation of the speeds of both conflicting vehicles (u_1+u_2) for each conflict with PET ≤5 sec as shown in Fig. 4.

[b)] Only for conflicts that have PET ≤ 5 sec.

2009. It is important to mention that during this period, there were no significant changes in the geometric and operational characteristics of the sites. The last column of Table 1 presents the total number of recorded severe crashes between vehicles that involve right-turners and resulted in injuries or fatalities.

After extracting the trajectories of last clearing right-turning vehicles and first entering through vehicles in each cycle using image processing program "TrafficAnalyzer" (Suzuki and Nakamura[16]), the position of conflict points, vehicle arrival time and vector speeds at these points are estimated. In this program, manually-tracked vehicle positions in the image data are transferred to world coordinates by projective transformation. Then, Kalman smoothing method is applied to estimate the vehicle speed. Table 2 presents the characteristics of observed conflicts at each site. Vehicle speeds for each conflict are represented as the summation of the estimated speeds of the conflicting vehicles at the conflict point since the severity of a conflict increases as the speed of any of the conflicting vehicles increases.



(a) PETs (b) Summations of conflicting vehicle speeds at conflict points

Fig. 2 The relationships between empirically estimated conflict characteristics and numbers of sever angle crashes at different signalized intersections

5. Empirical Analysis

Fig. 2(a) illustrates the relationship between observed PETs (≤5 sec) and number of severe crashes between right-turning vehicles and through traffic. There is no clear relationship between both parameters which clearly questions the ability of PET alone to represent the safety level of signalized intersections.

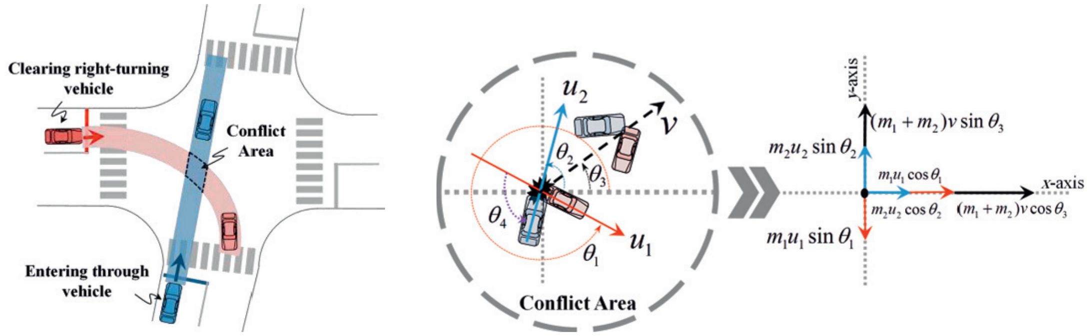
Fig. 2(b) illustrates the relationship between observed speeds of conflicting vehicles (summation of both conflicting vehicle speeds) and number of severe crashes. There is an increasing tendency in the number of severe crashes with the increase in the summation of conflicting vehicle speeds. However Taiko-dori 3 intersection behaves somehow different. Although it has a smaller summation of speeds compared to Sunadabashi and Suemori-dori 2 intersections, it has a larger number of severe crashes. This can be attributed to the observed PETs at Taiko-dori 3 which are lower than those at Sunadabashi and Suemori-dori 2. Lower PETs between conflicting vehicles means higher possibility of crashes. Therefore, using either PET or vehicle speed separately do not provide reliable safety assessment. This is also observed at Atsutajingu-minami intersection which has the largest number of severe crashes among the analyzed sites, although the estimated PETs are not significantly different from the other sites but rather higher in some cases. The reason could be the significantly higher vehicle speeds at conflict points that are observed at Atsutajingu-minami intersection. Higher conflicting speeds lead to higher possibilities of having severe crashes.

6. Proposed Conflict Index CI

To propose a measure capable of rationally representing the safety level of various conflict types, the main characteristics of any conflict; probability and severity should be considered simultaneously. The proposed index in this study is mainly based on the released kinetic energy after a collision. The released energy, which supposes to affect on the persons inside the vehicles, is a rational and reasonable indication of the expected severity level. The released energy is weighted by the probability of the collision to occur which is based on the Post Encroachment Time (PET). The proposed mathematical formation of the conflict index (CI) is shown in Equation (1).

$$CI = \frac{\alpha \Delta K_e}{e^{\beta PET}} \quad (1)$$

Where α is a parameter to represent the percentage of released energy that will affect the persons inside the vehicles, ΔK_e is the change in total kinetic energy before and after collision, the term $e^{\beta PET}$ is used to weight conflicts depending on the probability of a crash to occur. PET is defined as the time difference between two successive vehicles where the first vehicle clears the conflict area and the second arrives at the conflict area. As PET becomes shorter, the likeliness of the crash becomes higher. However conflicts of different types and surrounding conditions



(a) Angle collisions between right-turning and cross traffic (b) Momentum analysis along reference axis

Where u_1 is speed of the clearing right-turning vehicle (*m/sec*), u_2 is the speed of the entering through vehicle (*m/sec*), v is speed of clearing right-turning vehicle and entering though vehicle after collision (*m/sec*), θ_4 is the conflict angle, θ_1 is the angle between clearing right-turning vehicle and the positive x-axis at the conflict point (*degrees*), θ_2 is the angle between entering through vehicle and the positive x-axis at the conflict point (*degrees*), θ_3 is the angle between the collided vehicles and the positive x-axis after collision (*degrees*), m_1 is the mass of the clearing right-turning vehicle (*kg*) and m_2 is the mass of the entering through vehicle (*kg*).

Fig. 3 The estimation energy loss ΔK_e due to angle collisions

but with similar PET values might have different crash probability due to the location and size of conflict area. Therefore an adjustment parameter β (sec^{-1}) is proposed to reflect the effect of conflict type on crash probability.

Since the denominator is unit-less, CI has the unit of energy. Thus it represents the potential kinetic energy to be released if the conflict turned into a collision calibrated to the probability of collision occurrence. In reality, released kinetic energy due to a collision depends on many factors such as vehicle speed, type, shape, pavement condition, etc.

The advantage of this crash severity estimation mechanism using momentum conservation is to evaluate the condition after crashes from limited data by simple assumptions. Thus, the methodology is worthwhile although the actual crash mechanism is rather complicated.

6.1. Assumptions and Development

To estimate the change in kinetic energy ΔK_e before and after the collision, the following assumptions are made:

- The vehicles undergo a perfectly inelastic collision.
- The two vehicles move with the same speed together after the collision.
- The friction between the vehicles and the road can be neglected.
- The loss in energy reflects how much energy is released if the collision occurs.
- The system is isolated, where the momentum will be conserved.

To demonstrate how the proposed index is estimated, the conflict between clearing right turning vehicles (in left-hand traffic as operated in Japan) and entering though vehicles during the intergreen time is chosen as the basic conflict scenario for analysis and comparison. Fig. 3 illustrates the assumed kinetic energy concept after a collision. Since the collision environment is assumed as being isolated, the momentum is conserved along both reference axes as shown in Fig. 3(b). Thus Equations (2) and (3) can be derived. By solving these equations, the change in kinetic energy ΔK_e can be estimated as shown in Equation (4).

$$m_1 u_1 \sin\theta_1 + m_2 u_2 \sin\theta_2 = (m_1 + m_2) v \sin\theta_3 \quad (2)$$

$$m_1 u_1 \cos\theta_1 + m_2 u_2 \cos\theta_2 = (m_1 + m_2) v \cos\theta_3 \quad (3)$$

$$\Delta k_e = \left(\frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2\right) - \frac{1}{2}(m_1 + m_2) v^2 \quad (4)$$

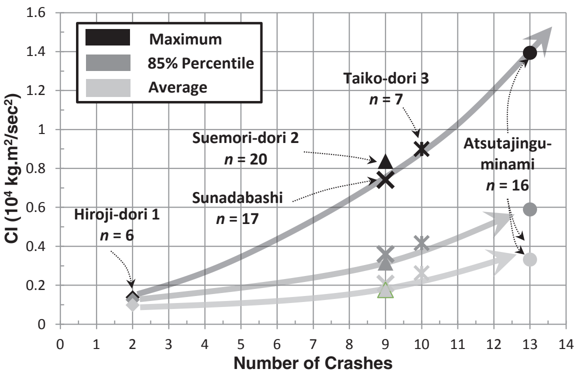


Fig. 4 The relationship between CI to number of severe angle crashes at different signalized intersections

The physical characteristics of vehicles such as weight, shape and cross-section affect the amount of released energy due to a collision. However in this study, vehicle weight is the only considered factor.

6.2. Setting of Parameters α and β

As defined in the methodology, α represents the percentage of the released energy that will affect the people inside the vehicles. It ranges between 0 and 1. This proportion depends on the speed of the conflicting vehicles, vehicle size and weight, vehicle body design and the presence of vehicle safety features such as airbags. For simplification, in this study it is assumed that all the released energy after a collision will directly affect the people inside the vehicles and thus α is assumed as 1.0.

Since crash probability is presented using PET, parameter β is an adjustment parameter for the crash probability considering conflict type. At a specific predicted PET between two consecutive vehicles, the probability of this conflict to become a crash might not be the same for various types of conflicts that have different traffic movements such as right-turning and left-turning, and different surrounding conditions such as lightening. Since in this study the conflict index is estimated for one type of conflict, thus β is assumed as 1.0.

7. Conflict Index Verification with Empirical Data

In order to investigate the reliability of the proposed index, extracted conflicts at observation sites are utilized to estimate CI. Only conflicts with PETs equal or less than 5 sec are considered and accordingly CI is estimated. Fig. 4 shows the relationship between estimated CI and number of severe crashes at the analysis sites. It clearly shows significant positive exponential relationships where the estimated CI increases as the number of sever crashes increases. The positive exponential relationship applies to the estimated maximum (R^2 = 0.994), 85th percentile (R^2 = 0.990) and average (R^2 = 0.950) CI values. This supports the reliability of the proposed index as a tool for conducting comparative safety analysis. However it is important to mention that the proposed index in its current form cannot be used to represent absolute crash frequencies at different sites.

8. Conclusion and Future Works

This paper aims to investigate whether existing safety measures such as PET and speed can rationally and reliably represent the safety levels of intersections in terms of crash probability and severity. For that several previously videotaped signalized intersections in Nagoya City are analyzed to estimate conflict characteristics which are compared with the recorded severe crashes during 6 years from January 2004 to December 2009. The analyzed conflict is the one between the last clearing right-turning vehicle and the first entering through vehicle of the following signal phase. By comparing the estimated vehicle speeds at conflict points and PETs with the recorded severe crashes, it is concluded that PET alone or vehicle speeds alone cannot be used to realistically compare the safety performance of different intersections, rather a combination of speed and PET.

Therefore, an assessment approach for intersection safety based on traffic conflict characteristics is proposed. A new safety measure "conflict index CI" that considers crash probability as well as severity is proposed. It mainly consists of the change in the total kinetic energy before and after the collision, and PET. As a result of the comparison analysis, it is found that the proposed safety index is successful in providing a similar ranking of different signalized intersection to that which is based on the number of severe crashes occurred at each site. Furthermore, it is found that estimated maximum, average and 85th percentile conflict indices have significant exponential relationships with severe crash numbers.

In general, the proposed index presents a rational blend between the probability and the severity of conflicts which can be used in comparison analysis. It can assess policy makers in prioritizing different sites for safety improvements projects. However comparison between estimated CI and long term crash records of different severities for various types of conflicts is necessary to provide concrete validation and reliable assessment on CI behavior under different conditions before being adopted as a safety assessment measure. Moreover, finding appropriate settings of parameters α and β is an important and challenging issue.

Acknowledgement

The author would like to acknowledge the support provided by the Deanship of Scientific Research (DSR) at King Fahd University of Petroleum & Minerals (KFUPM) for funding this work through project No. 131003. Furthermore, the author expresses his gratitude to Professor Hideki Nakamura of Nagoya University and his team for their great support in data collection and processing.

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