Quantifying the Severity of Traffic Conflict by Assuming Moving Elements as Rectangles at Intersection

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Abstract

To evaluate safety in intersections and find the relationship between conflict and accidents, a quantitative method for the severity of traffic conflict at intersection was proposed. Moving elements were assumed as rectangles. By using technology of imaging processing, kinematics parameters of vehicles were obtained. Supposed that movement units keep moving with current motion state, traffic conflict and time to collision (TTC) were determined using iterative method and analyzing positions of rectangles’ vertexes. According to the analysis of traffic conflict and brake performance of vehicles, non-complete braking time (TB) was selected to be critical value of conflict severity. Taking TTC and TB as parameters, quantitative value (Qs) was established. The severity of traffic conflict was quantified and classified by analyzing TTC and Qs. A case in Beijing was analyzed. The results indicated that quantitative result accorded with practical situation, and this method could be used in conflict detection and quantifying the severity of traffic conflict accurately.

Key Words: intersection safety; traffic conflicts; rectangles assumption; video detection; severity of conflict

1. Introduction

Intersection is the important hinge of highway and transportation system. Hence, safety condition of intersection plays a significant role in traffic system. In order to improve safety level of urban
transportation, intersection safety should be evaluated objectively. The traditional evaluation methods of intersection safety are mainly based on statistics of traffic accidents data. It is difficult, however, to evaluate safety in terms of the change in the number of traffic accidents at intersections, because traffic accidents are unpredictable and rare events (Jutaek, et al. 2010).

The evaluation method based on Traffic Conflict Technique (TCT) has attracted more attention in recent years. The general definition agreed upon for “traffic conflict” is: “an observable situation in which two or more road users approach each other in space and time to such an extent that a collision is imminent if their movements remain unchanged” (Tiwari, et al. 1998). Many researches about TCT have been carried out. While most conflict studies involved some form of conflict counts based on subjective observations of traffic interactions, there have been a few which made used of more quantitative measurements, in terms of time and space proximity between vehicles (Hoong-Chor and Ser-Tong, 1997).

With the development of computer technology and digital image technology, image processing, by which could obtain kinematics parameters of vehicles and pedestrians accurately, has also promoted the development of traffic conflict analysis.

In view of above mention, a new quantitative method for the severity of traffic conflict at intersection was proposed. To improve the precision of the model and quantitative results, moving vehicles were assumed as rectangles in this paper. By using technology of image processing, the kinematics parameters of vehicles including position coordinates, velocities, and accelerations were obtained. The quantitative method was applied in a field test in Beijing, China.

2. Literature Review

Mostly European and North American countries have designed and developed traffic conflict techniques. These countries have compared and field-tested traffic conflict techniques, and found them useful for diagnostic studies and short-term evaluations (Muhlrad, 1993). Kulmala (1993) discussed the role of TCT in safety analysis. He concluded that one should promote the traffic conflict technique as a complementary method to support crash studies so that one can achieve a complete picture of the traffic safety. Fruhman (1993) undertook a study to see the relevance between conflict data and traffic crash data. He also discussed the assessment of the safety quality for particular road users. With the extensive use of drive recorders (DRs), the application of the conflict technique has had wider coverage (National Highway Traffic Safety Administration [NHTSA] 2006, Lin et al. 2007, 2008). Lu et al. (2011) proposed a nonlinear model to describe the relationship between road traffic accidents and conflicts recorded by drive recorders, which makes it possible to estimate the accidents and evaluate the safety level by conflicts recorded. It was demonstrated by many researches that serious traffic conflicts would result in collisions, and the more serious a conflict is, the more likely an accident is going to happen. Therefore, it is important to do research on the severity of traffic conflicts, which is helpful in evaluating intersection safety condition, predicting traffic accidents and analyzing regression relation between traffic conflicts and traffic accidents.

The severity of traffic conflict refers to the possibility of traffic accident occurrence which is caused by traffic conflict. The conflict severity can be expressed by mathematical expectation of accident occurrence probability per time unit, and also can be shown by conflicts’ characteristics of themselves. Hayward (1972) had measured the severity of conflicts as the time-to-collision, or the time taken by the conflicted vehicle to collide into the offending vehicle if the speeds and paths of the both vehicles remained unchanged. Allen et al. (1978) and Cooper (1983) have employed gap time (the would-be time difference between arrival of the involved vehicles at the point of crossing if no evasive actions are taken) and post-encroachment time (time difference between arrival of conflicted vehicle and departure of offending vehicle at the point of crossing) for measurement of conflicts between crossing vehicles. Horst, van der
(1990) has considered different points at which time-to-collision should be measured. The time-to-
collision at the onset of braking (sometimes called time-to-accident) and the minimum registered value of
time-to-collision in an interaction process are two of the most commonly used quantitative measures in
2011 ). Although many quantitative measures of conflict severity are proposed, they have not been widely
used, largely because the data extraction process is rather time-consuming. However, there are indications
that the data extraction process can be made less labour intensive with increased use of computer
technology (Horst, 1989; Almqvist, 1989; Svensson and Odelid, 1993; Nicolas, et al. 2007). The use of
quantitative measures should be promoted.

Fortunately, recent developments in computer image processing (Svensson and Odelid, 1993) may
offer some promise in automating the labour-intensive procedure of kinematic data extraction. Nicolas, et
al. (2007) presented a vision-based system for road safety analysis. The system could automatically detect
traffic conflicts by processing video images and obtaining actual trajectories of moving objects. By using
image processing technology, Lu, et al. (2010) developed the program to detect kinematic parameters of
vehicles at intersection, and then proposed the quantitative method of conflict severity by assuming
moving elements as points (Lu, et al. 2011). However, most of existing image processing systems used in
traffic engineering are still not suitable for quantitative conflict analyses because they have been designed
primarily to obtain aggregated traffic information such as flow counts and traffic speeds rather than
kinematic information of individual vehicle movements. A major part of the problem lies in the poor
quality of the video images arising from imprecise vehicle images, which are very much affected by
variable lighting conditions at the site as well as background noise due to non-vehicle interference. All
these will naturally influence the accuracy of conflict measurements which is crucial for a quantitative
study.

Therefore, in this study, good quality of the video images were recorded, a more appropriate computer
program was developed by improving tracking module provided by OpenCV, and errors were reduced by
using Kalman filter. It is expected that the safety (danger) level at intersections will be assessed
henceforth using the developed program.

3. Quantitative Method

3.1. Research assumption

In previous study, moving vehicles were taken as points to quantify the severity of traffic conflict at
intersection (Lu, et al. 2011). Though it simplified the model and calculation, there was a big difference
between the actual situation and the presupposition above-mentioned. To improve the precision of the
model and quantitative results, moving vehicles were assumed as rectangles in this paper (Fig. 1).

Set the length of moving unit $i$ to $l_i$, and the width to $w_i$. The included angle between the side $DiAi$
and the positive direction of the x axis was set at $\theta_i$. To simplify the calculation, supposed that included angle
between the velocity direction of $i$ and the positive direction of the x axis was also equal to $\theta_i$ (Fig. 2).

At the initial time, set mass center’s state vector of unit $i$ to $X_i = (x_{i0}, y_{i0}, v_{ix}, v_{iy}, a_{ix}, a_{iy})^T$. Where,
$(x_{i0}, y_{i0})$ was mass center coordinate of $i$; $v_{ix}$, $v_{iy}$, speed in x direction, y direction respectively,
and $a_{ix}$, $a_{iy}$ was acceleration in x direction, y direction respectively.

At $t$ moment, set the mass center’s state vector of $i$ to $X_{it} = (x_{i}^t, y_{i}^t, v_{ix}^t, v_{iy}^t, a_{ix}^t, a_{iy}^t)^T$. Supposed
that movement unit keep moving with current motion state. Therefore, at $t$ moment, the mass center
coordinates of $i$ were calculated as
The mass center speed in $x$ direction, $y$ direction was calculated as

\[ \begin{align*}
    x_i &= x_{0i} + v_{xi}t + a_{xi}t^2 / 2 \\
    y_i &= x_{0i} + v_{yi}t + a_{yi}t^2 / 2
\end{align*} \tag{1} \]

And, the included angle between the velocity direction of $i$ and the positive direction of the $x$ axis was calculated as

\[ \theta_i = \begin{cases} 
\arctan\left(\frac{v_{yi}}{v_{xi}}\right) & \text{if } (v_{yi}/v_{xi}) \geq 0 \\
\pi + \arctan\left(\frac{v_{yi}}{v_{xi}}\right) & \text{if } (v_{yi}/v_{xi}) < 0 \\
\pi/2 & \text{if } v_{xi} = 0
\end{cases} \tag{3} \]

### 3.2. Conflict discrimination

Set the four vertexes of the motion unit $i$ to: $Ai(x_{Ai}, y_{Ai}), Bi(x_{Bi}, y_{Bi}), Ci(x_{Ci}, y_{Ci}), Di(x_{Di}, y_{Di})$, and the four vertexes of $j$: $Aj(x_{Aj}, y_{Aj}), Bj(x_{Bj}, y_{Bj}), Cj(x_{Cj}, y_{Cj}), Dj(x_{Dj}, y_{Dj})$. As shown in Fig. 3, if there is a...
collision between two movement vehicles, it is shown that one vertex of movement vehicle j will be on one side of the movement vehicle i, or one vertex of i will be on one side of j. Therefore, it can be used to discriminate traffic conflicts by tracking and analyzing the vertexes of motion units i and j.

Set $m = \frac{1}{2} \cos \theta$, $n = \frac{1}{2} \sin \theta$. According to the above assumptions, at $t$ moment, vertexes coordinates of $i$ may be expressed as

$$\begin{align*}
    x_i &= x_i + ml + nw_i, \\
    y_i &= y_i + nl - mw_i \\
    x_l &= x_i + ml - nw_i, \\
    y_l &= y_i + nl + mw_i \\
    x_j &= 2x_i - x_i, \\
    y_j &= 2y_i - y_i, \\
    x_n &= 2x_i - x_l, \\
    y_n &= 2y_l - y_l.
\end{align*}$$

If it could be estimated that one vertex of one vehicle would be on one side of the other after a period of time ($t$ seconds), it indicated that there was traffic conflict between two vehicles and Time to Collision (TTC) was $t$ seconds.

In this paper, to simplify the calculation, iterative method was chosen to determine traffic conflict and TTC. Short enough time interval ($\Delta t$) was selected. Based on the current state of two vehicles detected and Eq. (1) to Eq. (6) above, calculate all vertexes coordinates of two vehicles at different time in the order of \{ $\Delta t$, $2\Delta t$, $3\Delta t$, $4\Delta t$ ...$n\Delta t$ \} ($n$ was a large enough positive integer).

If it could be firstly detected that one vertex of Rectangle $AiBiCiDi$ would be in the interior or on the one side of Rectangle $A_jB_jC_jD_j$ (as shown in Figure 3.), or one vertex of Rectangle $A_jB_jC_jD_j$ would be in the interior or on the one side of Rectangle $AiBiCiDi$ at $k\Delta t$ moment, it suggested traffic conflict exists and TTC is $k\Delta t$ ($1 \leq k \leq n$). If there had no vertex of one rectangle in the interior or on the one side of the other rectangle from $\Delta t$ to $n\Delta t$, it indicated that TTC > $n\Delta t$.

Set $n=500$, $\Delta t=0.01s$. Then $n\Delta t=5s$. For non-signalized intersections in Beijing, China, most vehicles can leave intersections after 5s. Thus, this paper shown that there was no conflict between two rectangle units at intersection if TTC > $n\Delta t=5s$.

3.3. Quantifying the severity of traffic conflict

A good example of defining conflicts quantitatively is to represent conflicts as the nearness to a collision defined in terms of either space or time proximity between interacting vehicles. The closer the vehicles are to each other, either in time or space, the nearer they are to a collision, which occurs when...
both the time and space separations vanish simultaneously (Hoong-Chor and Ser-Tong, 1997). For a traffic conflict, the greater the difference in speeds or the smaller the spacing between the vehicles, the shorter will be the time-to-collision (TTC) and hence the more serious the conflict. Therefore, TTC also quantitatively specifies the severity of the conflict. However, since TTC decreases with increasing severity, it would be better to represent the conflict measure in terms of the reciprocal of TTC, which increases with increasing conflict severity. This definition also spells out the condition at which a conflict ceases (i.e., when the reciprocal of TTC becomes zero).

Furthermore, it is demonstrated that the severity of traffic conflict is also associated with brake performance of vehicles. And braking time to guarantee the traffic safety has motion the practical significance. It can synthesize reflection automobile braking performance. From the definition for “traffic conflict”, when the conflict begins, state of vehicles begins to change. In other words, when the conflict begins, braking begins to take effect. The longer the braking time is, the more likely the collision happens. Therefore, it is better to take non-complete braking time (TB) as critical value to determine conflict severity, because TB represents the period from the brake took effect to the vehicle stopped. If TTC>TB (i.e., when (TB/TTC) <1), the traffic conflict is serious. If TTC<TB (i.e., when (TB/TTC) <1), the conflict is non-serious. Set quantization value to Qs. Set Qs=TB/TTC. According to the above-mentioned, the relationship between conflict severity and Qs is shown in Table 1. The larger Qs is, the more serious the conflict is.

Table 1. Classification of traffic conflict severity

<table>
<thead>
<tr>
<th>Classification of traffic conflict severity</th>
<th>TTC(s)</th>
<th>Qs=TB/TTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>No conflict</td>
<td>&gt;5</td>
<td>0</td>
</tr>
<tr>
<td>Non-serious conflict</td>
<td>≤5</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Serious conflict</td>
<td>≤5</td>
<td>≥1</td>
</tr>
</tbody>
</table>

According to the theoretically analyzing of the braking process, non-complete braking distance (DB) is expressed as

\[ DB = \frac{V_o t}{2} + \frac{V_o^2}{2j_{\text{max}}} \]  

where \( V_o \) is instantaneous velocity of the vehicle; \( t \), the growth time of braking force, and \( j_{\text{max}} \) is the maximum deceleration.

Choose small-sized cars to study in this paper. Based on Vehicle Design Standards GB7258-87 and Motor Vehicles’ Inspection Standards set by Research Institute of Highway Ministry of Transport in China, \( t = 0.24 \text{s} \), and \( j_{\text{max}} = 7.4 \text{m/s}^2 \) for the small-sized car. Thus,

\[ DB = \left( \frac{V_o \times 0.24}{2} + \frac{V_o^2}{2 \times 7.4} \right) = 0.12V_o + 0.07V_o^2 \]  

Therefore, non-complete braking time (TB) can be expressed as

\[ TB = DB \left( V_o \right) = 0.12 + 0.14V_o \]  

Thus,

\[ Q_s = \frac{TB}{TTC} = \left( 0.12 + 0.14V_o \right) / TTC \]  

Eq. (10) shown that the higher the velocity was, the larger TB was. In other words, the higher the velocity was, the more serious the conflict was. Thus, in this paper, chose the higher velocity of two conflict units to calculate TB. As shown in Table 1, the severity of traffic conflict can be quantified and classified by analyzing TTC and Qs.
4. Data collection and method application

4.1. Data collection

In many previous studies on conflict, observers were repeatedly trained using video images to remove the subjectivity of the data collection, and their conflict observation results were compared with the results from the video images, based on which the conflict seriousness results were validated. After the training, conflicts are detected through the observers’ eyes. This method may cause many practical problems including observation errors in field applications, and is possible only in a laboratory and almost impossible in the field where very complicated traffic maneuvers exist, as the observer must be able to observe the diverse and complex traffic flows simultaneously and judge the seriousness of the conflict during the long-term observation. To avoiding these problems, in this paper, OpenCV and its built-in algorithm were used do video processing, including background extraction, blob detection, blob tracking, trail producing and trail post-processing. And then, the more stable kinematics parameters of movement units were obtained through Kalman filtering, accordingly, the determination of traffic conflict severity was realized. Processing flow is shown in Fig. 4.

4.2. Quantitative method application and results analysis

Experiment video was captured at one intersection in Beijing, China, whose frame rate was 25 frames/second. As shown in Fig. 5, two conflict units (Vehicle 17 and Vehicle 18) were chosen. Kinematics data of both units, including position, velocity and deceleration in each frame were obtained and saved by using the image processing above. Vehicle 17 and Vehicle 18 were detected from the 205th frame. Extract the kinematics data of Vehicle 17, 18 from the 206th frame to the 235th.

Set the length of both vehicles to 4.50m, and the width to 1.70m. Based on the kinematics data obtained and the quantitative method proposed, Time to Collision (TTC), non-complete braking time (TB) and conflict quantization value (Qs) were figured out.

The results shown TTC(s) was {0.61, 0.57, 0.43, 0.39, 0.25, 0.24, 0.26, 0.29, 0.38} from the 206th frame to the 214th. For the 215th frame to the 235th, TTC>5s, there had no conflicts in these frames. Based on the velocity detected and Eq. (9), TB(s) of the 206th - the 214th frames was {0.79, 0.71, 0.60, 0.55, 0.60, 0.38, 0.32, 0.28, 0.29}. According to Eq. (10), Qs was {1.29, 1.24, 1.39, 1.41, 2.38, 1.57, 1.22, 0.97, 0.76}. The change of Qs and deceleration of Vehicle 17 was shown in Fig. 6.

As shown in Fig. 6., Qs shifted from small to large, then large to small, and it could be demonstrated that the severity of the conflict between Vehicle 17 and Vehicle 18 rose first then dropped. The deceleration of Vehicle 17 rose at first, and then dropped. Largely because drivers realized the conflict and its danger, then took emergency brake measures to weaken the severity of traffic conflict, until the conflict resolved. This shown the quantitative results accorded with the practice, and the quantitative...
method of traffic conflict had effectiveness and practicability. Based on the classification of traffic conflict severity shown in Table1, it suggested that $Q_s \geq 1$ from the 206th frame to the 212th, conflicts were serious; $Q_s < 1$ in the 213th and the 214th frames, conflicts were non-serious; and $Q_s = 0$ from the 215th frame to the 235th, there was no conflict in these frames.

Fig. 5. The detection of movement objects

![Fig. 5. The detection of movement objects](image)

Fig. 6. The change of $Q_s$ and deceleration of Vehicle 17

![Fig. 6. The change of $Q_s$ and deceleration of Vehicle 17](image)

Conclusion

In this paper, taking TTC and TB as parameters, quantization value ($Q_s = TB/TTC$) was established and the severity of traffic conflict was quantified and clarified by analyzing TTC and $Q_s$. From a field test in Beijing, China, it was indicated that quantitative results accorded with practical situation, and this method could be used in conflict detection and quantifying the severity of traffic conflict accurately. It was believed that this study could be significant for the following reasons. First, it was an improvement of the past method of quantifying the conflict severity at intersection. By assuming moving elements as rectangles and using iterative method, quantitative results were more accurate. Second, the image processing technology used in this study eliminated the subjective errors of the observer and improved the efficiency.

Future works are, however, still needed to improve the conflict techniques developed in this study. Firstly, there are more conflict types that can be detected under other signal condition types such as permitted left-turns. Thus, conflict detection algorithms for various signal control types should be developed. Secondly, further studies are required on the image processing system. The image processing system used in this study uses the algorithms of OpenCV. In some cases, however, the data obtained is not enough accurate. Therefore, the image processing system must be continuously developed to meet the requirements and to increase the data accuracy.
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