

## Risk Assessment of Intersection Safety Countermeasures with the Use of Field Data

Ching-Yao Chan <sup>\*1</sup> Mikio Danno <sup>\*2</sup>

California PATH Program, University of California at Berkeley <sup>\*1</sup>

1357 S. 46<sup>th</sup> Street, Richmond, CA 94804, USA, TEL: 510-665-3621, E-Mail: [cychan@path.berkeley.edu](mailto:cychan@path.berkeley.edu)

Toyota InfoTechnology Center <sup>\*2</sup>

6-6-20, Akasaka, Minato-ku, Tokyo, 107-0052, Japan

### Abstract

In recent years, there have been world-wide interests in developing intersection collision avoidance systems. In such systems, computing, sensing, and communication technologies are utilized for the implementation of advanced driver assistance systems by issuing alerts to drivers in potential hazardous situations. To assess the effectiveness of proposed safety countermeasures, it is necessary to investigate whether the countermeasures can result in favorable and desirable driver responses. For the purpose of exploring design options and implementation issues of driver assistance functions, driver reactions can best be observed through the collection of field data in a real-world setting. This paper describes a study related to the collection, utilization and interpretation of field data. In addition, a criticality index function is proposed to quantify the safety risks in specific traffic scenarios. The availability of such risk index can be used to determine the safety impact of suggested collision avoidance systems.

**Keywords:** *Driver Assistance Systems, Intersection Collision Avoidance, Safety Risk*

### 1. Background

In the last few years, a number of research projects are initiated to pursue safety countermeasures for the reduction of crashes at intersections [1-6]. In the United States, a major project sponsored by US DOT for intersection safety, Cooperative Intersection Collision Avoidance Systems (CICAS), is underway [7] with a number of automobile industry, public agencies, and university participants. In Europe, the INTERSAFE project carried out within the European Community 6<sup>th</sup> Framework program was set out to develop intersection safety systems and algorithms that can provide accurate localization of the driver's vehicle and path prediction of other road users. In Japan, the government and industrial partners are testing the Driving Safety Support Systems (DSSS) [8], with field tests commencing in 2006, uses two-way communication devices set up near intersection to warn drivers of traffic signal transition, oncoming traffic, or pedestrians crossing.

The rationale for developing driver assistance systems with the aim to reduce collisions and improve roadway safety is built on the premise that driver factors are the primary cause of collisions, a well established fact [9]. Driver assistance systems can only be effective if they properly address the human factor aspects of driver behaviors. For example, if a driver intentionally violates a traffic signal even though he is aware of the risks involved, he may choose to ignore a warning issued through a driver assistance system. Thus, it is unavoidable that collision warning systems may only be

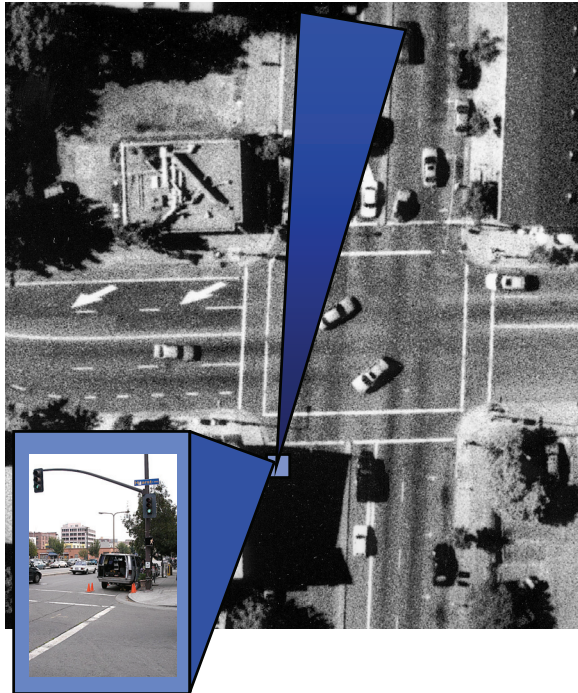
effective in certain conditions but not for all cases even if the systems function as designed.

Still, a majority of crashes occur due to the inattention misconception, or poor judgment of drivers in understanding traffic hazards. A central design issue involved in such situations is the ability of drivers to assess safety risks under various traffic conditions. Accordingly, driver assistance systems can then provide timely and robust warnings to drivers without interfering or confusing the drivers' own judgment. When traffic conditions warrant the issuance of a warning, a message is communicated to the driver with the intention that he or she will react in favorable and timely manners so that crashes can be avoided or mitigated. Therefore, it is essential that warning criteria and associated algorithms implemented in the suggested driver assistance systems provides proper assessment of situational threat that is acceptable to drivers.

In light of the criticalness of threat assessment for the aforementioned reasons, the work reported in this paper was carried out to explore the risk indices for the determination of safety risks in intersection traffic scenarios. Section Two provides a description of field data collection for the purpose of understanding traffic patterns and driver behaviors in real-world situations. A sample set of data was used to illustrate the extraction of traffic phenomenon from field observation. Section Three offers a review of several risk indicators that are commonly referenced and a discussion of their applicability in various traffic scenarios. Subsequently,

a newly proposed risk indicator, Criticality Index, is proposed for left-turn across-path, opposite-direction (LTAP-OD) scenarios, to incorporate the severity and timing of a potential conflict.

## 2. Data Collection Methodologies



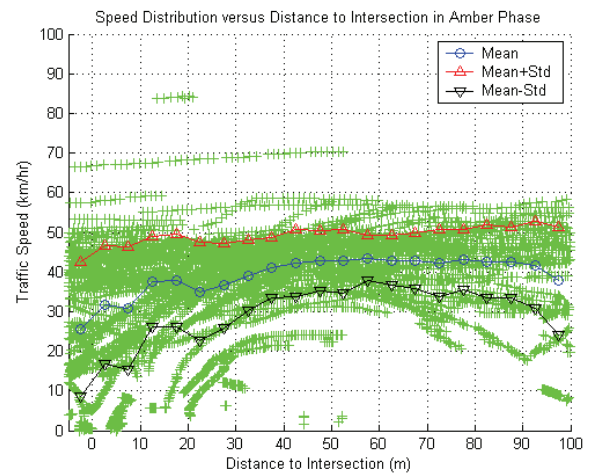
**Figure 1 Schematic Diagram of Data Collection Setup**

As an important part of the studies in these intersection safety systems, considerable efforts have been dedicated to the observation and testing of driver decisions and response under various traffic conditions. For example, a methodology was developed at PATH to rely on field observations to facilitate the understanding of driving behaviors in intersection turning scenarios [10-13]. Figure 1 depicts an exemplar setup at an intersection for filed data collection. A mobile platform, consisting primarily of a radar sensor and a data acquisition computer, was stationed at selected intersections. The radar was oriented to capture the oncoming traffic, as indicated by the blue triangle that represents the coverage area of the radar.

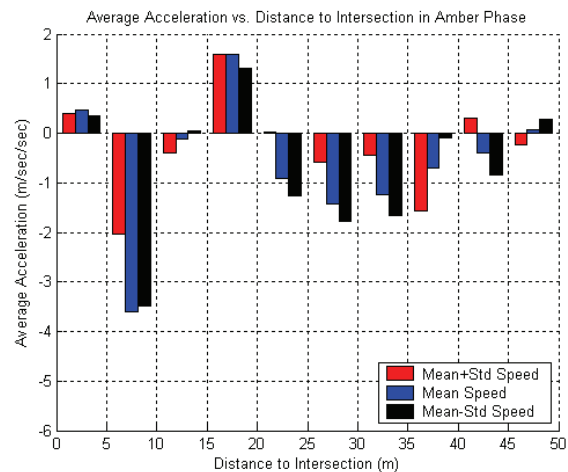
Figure 2 displays a sample set of traffic data with a plot of the approaching speed of detected vehicle as a function of their distance to the stop line at the intersection. This data set was captured during the amber phase of the traffic signal, which has duration of 3.3 seconds at this intersection. Each data point sampled at 0.075 second intervals is plotted as a green dot in the figure. For every 5-meter segment in distance to the stop bar at the intersection, statistical analysis was

performed for all data points within each segment. The mean values, and mean plus or minus one standard deviation, were then plotted in the figure to illustrate their distribution in each 5-meter section.

It should be noted that the data points shown in Figure 2 is a collection of all moving targets detected by the measuring radar. Therefore, some targets moving out of roadside parking locations or coming out of side streets or driveways will be included as well. As a result, even though the majority of data points reflect the typical traffic flow patterns, some exceptional cases are illustrated as well. For example, in the range of 90-100 meters, most targets are cruising at relatively constant speeds, but there are a few targets changing speeds quite significantly.



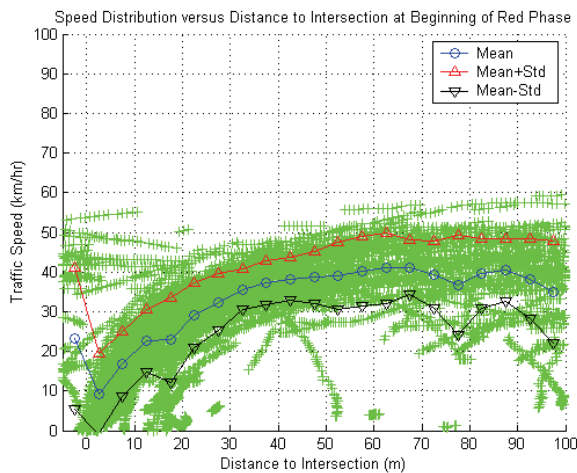
**Figure 2 Vehicle Speed vs. Distance in Amber Phase**



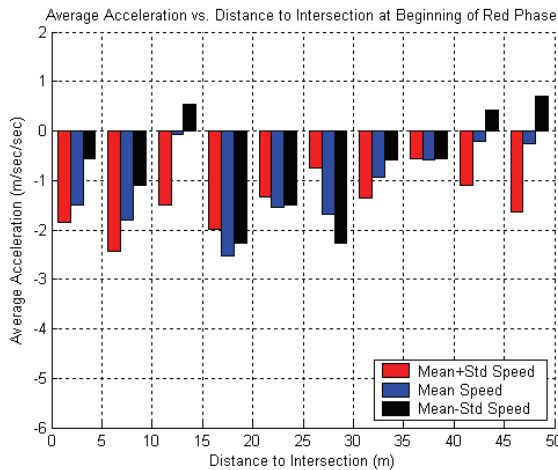
**Figure 3 Deceleration Based on Average Speed in Amber**

Using the three piece-wise linear curves, representing the mean and one-deviation distribution, in Figure 2, the

“average” decelerations for each 5-meter segment were estimated and plotted in Figure 3. A positive value on the vertical axis implies an accelerating action, while a negative value indicates a braking or stopping action. For example, in the section of 20-25 meters, the average action is to slow down and to prepare for a stop. At the 10-20 meter range, there is a neutral or accelerating action. The neutral and accelerating actions in the 10-20 meters reflect the probable patterns of traffic movements in the so-called dilemma zone. Within the section of 5-10 meters, there are very obvious stopping actions, which reflect the situations of hard braking for those vehicles close to the stop line.



**Figure 4 Vehicle Speed vs. Distance in Initial Red Phase**



**Figure 5 Deceleration Based on Average Speed in Initial Red Phase**

It should be noted that the data utilized in the paper is based on real-world field speed measurements by radar devices. The deceleration values, if derived directly for each target, become very noisy with significant fluctuations over time for each target. Since the radar of

Doppler type used in field measurements is reasonably accurate with speed measurements but cannot offer reliable acceleration measurements, the values derived from speed distribution is used instead.

Figure 4 and 5 are similar illustrations for the initial 4.5 seconds in the red signal phase. Only the initial period of the red phase is included in the plot, because the actions of vehicles arriving later in time will be affected by those already stopped at the stop line. A comparison of the data in the amber and the initial red phases shows that there is more evenly distributed use of braking in the red phase than in the amber phase. This is particularly apparent in the near range closer to the intersection.

The data presented in the figures above are based on a roadside collection method, which allows the identification of traffic patterns at a specific location. A relatively large number of samples can be obtained within a short period of time. By deploying the mobile equipment platform, data collection at multiple sites can be carried out for comparative studies. However, this technique does not provide in-vehicle monitoring of individual drivers. For more comprehensive data sets, a combination of roadside and onboard data acquisition will be necessary. An earlier study [11] provided a description of utilizing roadside and in-vehicle data for the investigation of traffic interaction and driver reactions to traffic conditions. Combined roadside and vehicular data are more suitable for thorough identification and interpretation of traffic phenomena.

### 3. Risk Index Function for Evaluating Situational Conflicts

Several categories of risk indices are commonly used in evaluating the potential of a collision. In this section, an overall review of quantifying the risks involved in intersection maneuvers and associated conflicts is given. Then, more specific method of utilizing data acquired in field observation for quantifying safety risks will be presented in the next section.

Time to collision (TTC) was a popularly used measure for rating the severity of conflicts [14]. Hayward defined TTC as the time required for two vehicles to collide if they continue at their present speed and on the same path. If an evasive action is taken, then TTC represents available maneuvers space. The minimum TTC as reached during the approach of two vehicles on a collision course is taken as an indicator for the severity of an encounter. After its initial introduction, TTC was widely cited and accepted as a useful indicator in evaluating collision risks. For example, in more recent work, Horst [15] adopted TTC as a measure for

evaluation of intersection collisions for the application of collision avoidance system. Horst and Hogema [16] extended the work and investigated the use of TTC measure to define an adequate criterion for activating a driver support system such as rear-end collision avoidance systems. It was reported in that study that the testing of Collision Avoidance Systems (CAS) indicate that warning strategies based on a TTC-criterion are preferred by the drivers and seem to be most in line with what drivers expect to get from a CAS.

However, intersection collision types are quite diverse and there are several issues in the direct application of TTC to intersection maneuvers. TTC is easier to define and quantify for rear-end collisions such as in car following scenarios. When the trajectories of two vehicles in conflict do not cross at the present time, then there is little meaning in referring to TTC. Furthermore, the value of TTC is sensitive to the relative speed of two approaching vehicles. A slight change in relative speeds will lead to drastic fluctuations in TTC. Moreover, the instantaneous value of TTC reflects no uncertainties of the dynamic situations. To overcome this deficiency, Wakabayashi [17] proposed an amended risk index, Potential Time to Collision (PTTC) to take into account the variability of TTC. Specifically, PTTC aims at the handling of car-following scenarios when TTC is infinite with two vehicles traveling at the same speed, regardless of the spacing and the absolute speed. The key difference in this revised index is the incorporation of the leading vehicle's acceleration to account for the probable conflicts with a change in situations.

Allen [18] suggested the use of Post-Encroachment Time (PET). PET is the time of a vehicle traveling to a location where another vehicle once occupied. PET between straight vehicles from two adjacent approaches is chosen as a measure for the degree of hazard of right-angle collisions at intersections. To measure PET, it is necessary to know only two points in time: (a) when the first vehicle leaves the right-of-way infringement zone; and (b) when the second vehicle enters the right-of-way infringement zone. It is considered a near-miss indicator and it seems to be a preferred alternative to TTC for crossing-path maneuvers.

In more recent work [19], a practical method was proposed to evaluate the frequency of right-angle collisions based on a frequency of short PET. PET and crash data collected from signalized intersections in Indiana were used to calibrate right-angle crash prediction models. Regression analysis results reveal that PET frequency is a key determinant of right-angle crashes and is capable of discriminating varying safety levels within a location as well as across locations. Several evaluation examples are presented in that study

to illustrate how the method can be used and how the estimation results can be interpreted.

In the case where the leading vehicle is moving faster than the following vehicle, the instantaneous TTC index will be of an infinite number. Even though this reflects a non-threatening situation, there are conditions when a realistic hazard still exists, especially when the distance between two vehicles is very short. To handle such situations, a slightly different approach, called Potential Index for Collision with Urgent Deceleration (PICUD) was suggested by Uno et al. [20] PICUD is an index to evaluate the possibility that two consecutive vehicles might collide assuming that the leading vehicle applies its emergency brake. PICUD is defined as the distance between the two subject vehicles when they come to a completely stop. PICUD is constructed to evaluate the potential danger of rear-end collision. Estimation of PICUD requires two predetermined parameters: (1) reaction time of drivers and (2) deceleration rate of vehicle.

All the aforementioned indices proposed for evaluating safety risks of traffic scenarios offer good criteria for suitable situations when they are applicable. However, there are limitations in their use for the type of intersection collisions that are being considered and targeted in the current research efforts for CICAS, including either straight-crossing or across-path conflicts. A newly proposed risk index is elaborated and described in the following sections.

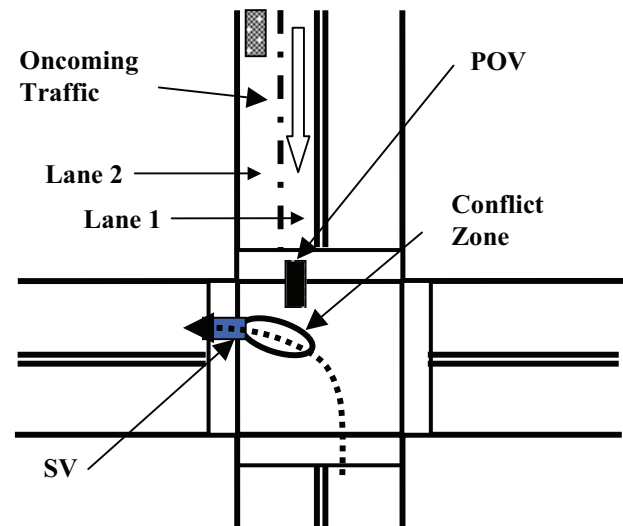


Figure 6 Schematic of LTAP-OD Conflicts

#### 4. Quantifying Risks for Intersection Conflicts in Crossing-Path Turning Maneuvers



One high-risk scenario at intersections is the so-called Left-Turn Across-Path Opposite-Direction (LTAP-OD) situation. A diagram depicting such situations is given in Figure 6. The LTAP-OD conflict occurs when a subject vehicle (SV), while making a left turn, encounters a threat presented by an approaching principal other vehicle (POV). POV refers to the opposing vehicle that is most likely to be in conflict with SV due to its closeness in distance or time.

Among those surrogate measures that are described in the previous section, there are certain shortcomings of respective risk indices for their usage in the LTAP-OD scenarios. For example, TTC is primarily based on the closing speed of two vehicles that are expected to close the gap in between. However, TTC is not meaningful if the projected trajectories of the two vehicles do not intersect at the present time. PTTC is designed to handle similar situations while taking into account the potential deceleration applied by the leading vehicle. Such indices are not suitable for LTAP-OD scenarios. In a “close-call” risky situation the SV and POV may come close to each other in time when they pass through the conflict spot, but there is no gap to close because the two vehicles are moving in different spatial trajectories.

On the other hand, PET is based on the arrival times of the two vehicles at the potential collision location in space. PET is difficult to assess if the projected intersecting point of the two vehicles keep changing. However, it will be suitable for assessing the crossing-path situations as the LTAP-OD conflict occurs at a well-defined location (the conflict zone shown in Figure 6), even if the trajectory intersecting point may not be exact. For simplification of discussions in the following sections, the conflict zone will be designated as the point of conflict (POC) where the trajectories of SV and POV cross.

#### 4.1 Use of Trailing Buffer for Measuring Risks

In earlier studies, a methodology was presented to derive the distribution of accepted time gaps and the trailing buffers among a group of drivers in field observations [10, 11]. It was suggested that such knowledge of driving behaviors could be used as the baseline in deciding the appropriate criteria in issuing a warning to the drivers in CICAS-SLTA types of countermeasures, if warranted.

Specifically, for the use of “buffers” in LTAP-OD situations, the definitions of terminologies should be clarified:

- An observed time buffer is defined as the time period between the instant of POV passing through the conflict point and the instant of SV arriving at the conflict point.
- In the case of POV arriving earlier than SV, the time interval between POV passing through the point of conflict (POC) and the later arrival of SV at POC is called the leading buffer.
- In the case of POV arriving later than SV, the time interval between SV passing through POC and the later arrival of POV is called the trailing buffer.
- POV and SV actions are continuously influenced by the driver actions, likely in response to traffic conditions and signal phases, therefore their trajectories and relative arrival times are dynamic. As a result, the estimated time buffer varies during the vehicles’ approach toward the intersection.
- In accordance with the dynamic nature of such vehicle interaction, the estimated buffer is an instantaneous value, called the projected buffer (PB) hereafter, that may change over time.
- Using the following definition of buffers, “Buffer = POV arrival time – SV arrival time at POC,” then a leading buffer has a negative value and a trailing buffer has a positive value.

Figure 7 shows the arrival times of POV versus the arrival time of SV for a number of cases in a selected time period. The vertical axis shows the projected time interval needed for POV to arrive at the point of conflict, which will be denoted as POV-TTPOC (POV Time-to-POC). The horizontal axis indicates the time intervals before and after SV arriving at the point of conflict. The data plotted were taken from a set of field traffic data at one observation site. The two colors of markers in the plot differentiate the POV position in Lane 1 or Lane 2 in their approach toward the intersection. Lane 1 (inside lane) corresponds to the lane in Figure 6 where the long arrow showing the traffic flow direction is placed, while Lane 2 (the outside lane) corresponds to the lane where the gray-shaded target further away from the intersection is located.

For each scenario of SV-POV interaction, the plotting of the POV time trajectory in Figure 7 and the computation of buffers are conducted in the following steps:

- (1) When a SV is observed to make a left turn, the time instant of its arrival at the point of conflict is marked as “time = 0” for that particular case.
- (2) For this particular case, eight seconds before and four seconds after time 0, all opposing vehicles are identified. This is accomplished by monitoring the opposing traffic and measuring the speed and distance of approaching vehicles.
- (3) The closest vehicle in time (the POV) is identified. The estimated arrival time of this POV is calculated by dividing the distance to the point of conflict by the approaching speed.
- (4) The estimated time for POV to arrive at POC (POV-TTPOC) is plotted in Figure 7 to show how the estimated arrival time varies versus the time instant

when the SV crosses over the point of conflict (time = 0).

- (5) The projected time buffers are calculated as the time differential when POV is projected to reach the point of conflict versus time = 0.

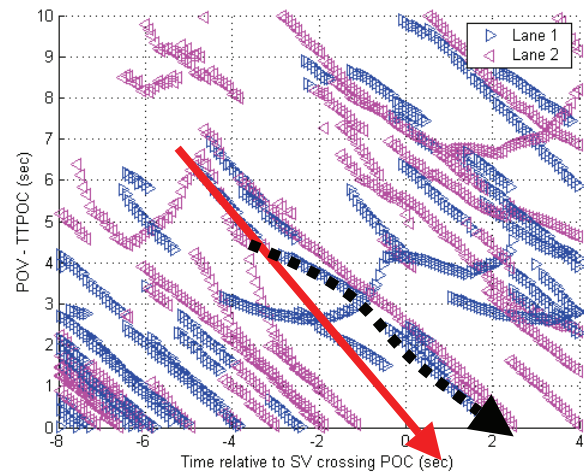
As can be seen in Figure 7, the actions of POV can dictate how its time trajectory changes.

- (1) If the POV continues to cruise toward the intersection with a constant speed, the time trajectory in Figure 7 will be a straight line with no change in its slope. Note that a down-sloping linear line is showing the change of POV-TTPOC over time. In other words, the slope will stay constant if the speed of the POV does not vary over time. For example, if a POV is four seconds away from the POC, then one second later the POV will be “three seconds” away from POC. Similarly, two seconds later, the POV will be “two seconds” away. Therefore, this can be equally applied to POV moving at other speeds. Therefore, a down-sloping line in Figure can be representative of a fast or slow moving POV, regardless of their speeds.
- (2) If the POV slows down in its approach toward the intersection, then the slope of the time trajectory flattens with a slope of smaller absolute values. This type of actions can be seen in several Lane-1 POVs in the middle and on the left side of the chart.
- (3) If the POV accelerates, then the time trajectory steepens. This can be seen on a couple of Lane-2 POVs on the middle-lower left portion of the chart.

By observing a line or a trace of a POV in motion, the potential risk of a conflict can be evaluated. For example, a number of POV arriving with a leading (negative) buffer were shown in the lower left corner of the chart, while several other POV arrive later with a trailing buffer of 2 seconds or more. A few additional observations can be noted on the chart:

- No POV came close to SV (at  $t = 0$ ).
- However, a POV target that was present at  $t = -4$  is projected to follow the dotted line to arrive at the same time as SV if the trajectory is unchanged.
- If the POV continued to follow the red-dotted line, it would have come into a conflict or a collision because both POV and SV arrived at POC at the same time.
- In actuality, that POV slowed down and the trajectory was changed to follow the solid arrowed line.
- The actual trajectory following the black dotted line resulted in a trailing buffer of approximately 2 seconds. As illustrated for this scenario, the projected buffer (PB) varies over time and turns an

originally more risky situation into a non-threatening one.



**Figure 7 Dynamic Buffer Variations**

Using the buffer values, the risk for a potential conflict is captured by the differences in arrival times of the vehicles involved. Therefore, the leading and trailing buffers adequately reflects the safety risks of potential risks. However, because of the dynamic nature of the buffer values, they must be continuously monitored if a real-time warning system is to be implemented for timely and reliable alerts to the drivers.

Upon inspection of all risk indicators reviewed above, it is found that all safety risk indices so far focus more on the time factors of a potential conflict but the severity of a potential collision is not taken into account. The lack of such information fails to identify and differentiate hazardous situations where the outcome of the conflict can be drastically different. For example, two potential conflicts with the same values of TTC, PET, or Trailing Buffers may involve vehicles traveling low or high speed differentials, which can have a significant impact on the consequences. In a more severe case, the speed differential may lead to a fatal crash while the modest case will result in property damage only. These situations clearly differ on the criticality of an alert to the drivers and should be considered in the design and implementation of safety countermeasures. A concept of a criticality index was initially introduced by Chan [12], and will be further elaborated below for the calculation and utilization of such index.

In order to capture the severity of a potential collision, especially for LTAP-OD scenarios, a risk index is proposed to be a function of the collision speed and the trailing buffer. The rationale is as follows:

- The severity risk is proportional to the kinetic energy involved in a crash. From the SV

perspective, the most threatening situation is a collision with POV hitting the side of the SV as it makes the turn. Therefore, the severity can be estimated by the oncoming speed of the POV.

- The timeliness of an alert to SV drivers can be judged by the probability of avoiding a conflict, which in turn is a function of the time available before the eminent collision occurs. Therefore, it is suggested that the risk is inversely proportional to the projected time buffers associated with the potential collision.
- In the LTAP-OD cases, the ability to avoid collisions can be estimated by the length of the leading or trailing buffer. In other words, if the time differential of the arrival times of POV and SV is large then the risk is low, and vice versa.
- A Criticality Index is defined to be equal to  $V^2/\text{Abs}(\text{Projected Buffer})$ , where the denominator is the absolute value of the difference in arrival times, and  $V$  is the appropriate speed of POV.
- When metric units are used, a POV speed of 10 m/sec (22 mph) with a projected time buffer of 1 second will yield a criticality index of 100. A POV speed of 20 m/sec (44 mph) with a projected time buffer of 4 seconds will also have an equivalent criticality index of 100.

Note that the criticality index will have a unit of  $\text{m}^2$  divided by  $\text{s}^3$ . Some probable interpretations of the physical unit for this index is as follows:

(1) A direct explanation is from its definition, that is the criticality index is a representation of the POV kinetic energy divided by the time gap between the SV-POV cross maneuver.

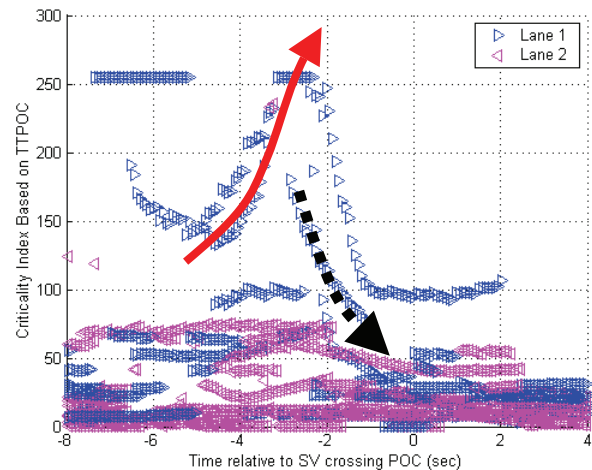
(2) The index can also be expressed as  $V*(V/\delta t)$ , where  $\delta t$  is the time gap to a potential collision. Thus, if an evasive action is need to brake and bring the vehicle to a stop ( $V=0$ ), then  $V/\delta t$  is equivalent to the required deceleration to do so. In other words, the criticality is a product of the POV speed and the necessary deceleration to avoid a collision.

(3) By another definition, momentum is the derivative of kinetic energy,  $M = d(mV^2/2)/dt$ , where  $M$  is momentum and  $m$  is target mass. As a result, since  $V*(V/\delta t)$  or  $V*A_{\text{req}}$  is also a representation of momentum change, the criticality index is the required momentum change to avoid a collision.

This concept of conflict severity incorporated into a risk function is illustrated in Figure 8. The figure is generated with the same set of field data utilized in Figure 7, where a number of SV-POV interactions were involved.

The criticality index value is calculated according to the formula described above, Criticality Index =

$V^2/\text{Abs}(\text{Projected Buffer})$ . However, for plotting purposes, the value is truncated and capped at 250 in Figure 8. As shown in the chart, most of the SV-POV interactions have relatively low index values below 50. Sometimes, the index value rise due to the projected short buffer in their encounters. As long as the POV speed or and the projected buffer are unchanged, the index value will also stay stable. Occasionally, high index values will emerge due to a very small projected buffer.



**Figure 8 Criticality Index Value Variations**

Using the same case illustrated in Figure 7, two dashed lines referring to the same pair of POV-SV interaction are drawn. Originally, as the POV is projected to arrive at POC at the same time as SV, the index value rises rapidly. When the POV slows down and changes its trajectory and the projected buffer becomes larger, the criticality index drops significantly. The variations of criticality index values, as shown in Figure 8, properly reflects the risk of a potential conflict as shown in the buffer variation of Figure 7. In addition, with the introduction of POV speed into the criticality index, the risk function now contains information about the probable consequence in the conflict.

Notice that in the evaluation shown in Figure 7, while the trailing buffer correctly reflects the “closeness” of a potential conflict or a collision, it tells nothing about how severe a collision may be. In other words, a fast moving POV or a slow POV cruising toward will show with the same down-sloping straight line. If their closeness in time relative time = 0 is the same, then the trailing buffer will be the same as well. An alternative will be to include the distance of POV to the conflict point as part of the calculation, but either parameter alone does not reveal the complete picture of the conflict. In contrast, if the criticality index as suggested is used,

the severity of the potential collision and the closeness in time are both included in the risk function.

In summary, for the assessment of safety risks in traffic scenarios it is necessary to define and select appropriate risk indicators. To overcome some of the shortcomings in previously suggested and commonly adopted risk indicators, an alternative form of risk function is suggested for intersection LTAP-OD scenarios. This risk indicator has the advantage of including the severity and the time urgency of a potential collision. A case study was shown to illustrate the calculation and interpretation of the criticality index with sample data from field observation. The results show that the risks reflected by the measures of projected time buffers and criticality indices are consistent and suitable for the judgment of a potential conflict. Such indicators can be jointly used with trailing buffers to form the basis in warning criteria for the intended safety applications.

## 5. Concluding Remarks

This paper contains the evaluation and applicability of risk indicators for intersection traffic scenarios. First, a data collection method for observing traffic patterns is introduced. Next, commonly referenced risk indicators for collision avoidance systems were reviewed to address their suitability for the intended intersection applications. Subsequently, a criticality index function is proposed to overcome certain shortcomings of the existing risk assessment tools. The use of field data to estimate and assess the risks involved in LTAP-OD scenarios was illustrated.

The techniques of risk estimation explained in this paper can be used in the following manner. The utilization of data from field observation offers a realistic baseline for estimating risks accepted in specific maneuvers at intersections by a population of drivers. The results from the study allow the quantification of driver risk-taking behaviors in left-turn across-path scenarios. Then, the interpretation of such behaviors can serve as the basis for determining if a warning should be issued under similar situations. If significant samples are taken from a diverse set of intersection, the guidelines for adjusting warning criteria can then be systematically established.

An extended effort of field observation is continuing in the efforts during the ongoing CICAS project. Additionally, at the completion of prototype developments, field operational studies will be conducted to observe the robustness and effectiveness of proposed safety solutions. The collection and additional field data is a primary topic of future studies.

## Acknowledgment

This work was performed as a joint effort between the two authors, when the first author serves as a visiting Professor at the University of Tokyo in 2006. The authors would like to thank the support and accommodation of their respective institutions. The contents of this paper reflect the views of the authors, who are solely responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the associated organizations.

## References

- [1] Misener, et al, "Toward a Smarter, Safer Intersection: Application of Intelligent Countermeasures to the Intersection Crash Problem," *ITS World Congress*, Madrid, Spain, Nov. 2003.
- [2] Schagrin, M., "Cooperative Intersection Collision Avoidance Systems Initiative," Presentation at Intelligent Transportation Systems America Annual Meeting, May 2005.
- [3] Fuerstenberg, K.C., "Intersection Driver Assistance System - The EC project INTERSAFE," 13th World Congress & Exhibition on Intelligent Transport Systems, London, United Kingdom, October 2006.
- [4] Schulze, M., "PREVENT: Prevention and Active Safety Application to Improve Traffic Safety," "IEEE Intelligent Vehicles Symposium, Las Vegas, June 2005.
- [5] Oda, T., Tajima, T., "Driving Safety Support System for Senior Society," *ITS World Congress*, Toronto, Canada, October 1999.
- [6] Yamamoto, S., Mizutaru, K., Seto, M. "AICHI DSSS (Driving Safety Support System) Field Verification Test," 13th World Congress & Exhibition on Intelligent Transport Systems, London, United Kingdom, October 2006.
- [7] <http://www.its.dot.gov/cicas/>, US DOT CICAS Website.
- [8] <http://www.utms.or.jp/english/system/dsss.html>, Japan UTMS DSSS Website.
- [9] Evans, L, "Traffic Safety," 2<sup>nd</sup> Edition, 2004.
- [10] Chan, C-Y, et al., "Observations of Driver Time-Gap Acceptance at Intersections in Left-Turn Across-Path Opposite-Direction Scenarios," TRB Transportation Records, No. 1910, pp. 10-19.
- [11] Chan, C-Y, "An Investigation of Traffic Characteristics and Their Effects on Driver Behaviors in Intersection Crossing-Path Maneuvers," IEEE Intelligent Vehicles Symposium, to be held in Istanbul, Turkey, June 2007.
- [12] Chan, C-Y, "Defining Safety Performance Measures of Driver-Assistance Systems for Intersection Left-



Turn Conflicts,” IEEE Intelligent Vehicles Symposium 2006, Tokyo, Japan, June 2006.

- [13] Chan, C-Y, Bougler, B., “Evaluation of Cooperative Roadside and Vehicle-Based Data Collection for Assessing Intersection Conflicts,” IEEE Intelligent Vehicles Symposium 2005, Las Vegas, June 2005.
- [14] Hayward, J.C., “Near Miss Determination through Use of S Scale of Danger,” Report No. TTSC 7115, The Pennsylvania State University, 1972.
- [15] Horst, A.R.A. van der, “Time-to-Collision as a cue for decision-making in Braking,” Vision in Vehicles III, Elsevier Science Publishers B.V., edited by Gale, A.G. et al., Amsterdam 1991, pp. 19-26.
- [16] Horst, A.R.A. van der, Hogema, J., “Time-to-Collision and Collision Avoidance Systems,” ICTCT Workshop, Salzburg, Austria, 1993.
- [17] Wakabayashi, H., et al., “Traffic Conflict Analysis using Vehicle Tracking System: Digital VCR and Proposal of a New Conflict Indicator,” Journal of Infrastructure Planning, Vol. 20, No. 4, pp. 949-956, 2003.
- [18] Allen, B.L., Shin, B.T., Cooper, D.J., “Analysis of Traffic Conflicts and Collision,” Transportation Research Record, No. 667, pp. 67-74, 1978.
- [19] Songchitruksa, P., Tarko, A.P., “Estimating Frequency of Right-Angle Collisions at Traffic Signals – A Practical Method,” Transportation Research Board Annual Meeting, TRB 06-1083, 2006.
- [20] Uno, N., et al., “Objective Analysis of Traffic Conflict and Modeling of Vehicular Speed Adjustment at Weaving Section,” Journal of Infrastructure Planning, Vol. 4, No. 4, 2003, pp. 989-996, 2002.

## Author Biography



**Ching-Yao Chan** is researcher with the California PATH Program at the University of California, Berkeley. Chan receives his bachelor degree from National Taiwan University, and Master and Ph.D, degrees from the University of California at Berkeley. He has extensive experience in the subject areas of automotive safety and intelligent transportation systems.



**Mikio Danno** is a senior researcher with TOYOTA InfoTechnology Center in the technology research area. Danno has received his Master's degree in Economics from Bombay University. He is an Individual member of ITS Japan.

- *Received date: 1 August 2007*
- *Received in revised form: 1 November 2007 and 23 January 2008*
- *Accepted date: 24 January 2008*
- *Editor: Hiromitsu Kumamoto*