Transportation Planning and Technol., Vol. 22, pp. 309–323
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TRAFFIC CONFLICT STANDARDS FOR INTERSECTIONS

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(Received 26 March 1998; In final form 27 October 1998)

This paper describes the application of the traffic conflict technique to estimate, traffic safety at intersections. Using data collected from 94 conflict surveys, traffic conflict frequency and severity standards for signalized and unsignalized intersections have been established. These standards allow for the relative comparison of the conflict risk at various intersections. An Intersection Conflict Index (ICI) measure was developed to summarize conflict risk and provide an indication regarding the relative risk of being involved in a conflict at an intersection. In addition, regression analysis was used to develop predictive models which relate the number of traffic conflicts to traffic volume and accidents. The regression analysis results indicate that: (i) the average hourly conflict rate (AHC) and the average hourly severe conflict rate (AHC 4+) correlated reasonably well with traffic volume for both signalized and unsignalized intersections, and (ii) strong relationships between accidents and conflicts were obtained for signalized intersections only. These research efforts are expected to further enhance the usefulness of the traffic conflict technique as a tool to evaluate the safety of intersections. Finally, a case study is presented as an example of the usefulness of traffic conflict analysis.

Keywords: Traffic conflicts; Traffic accidents; Conflict measures; Conflict standards; Intersection safety

INTRODUCTION

Traffic accidents at intersections are pervasive road system failures, yet our understanding of the failure mechanism is poor, which reduces the accuracy of road safety diagnosis and the estimation of countermeasure

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effectiveness. Traffic safety analysis for intersections has often been undertaken using historical accident data. However, there are well-recognized availability and quality problems associated with accident data. In addition, the use of accident records for safety analysis is a reactive approach: a significant number of accidents have to be recorded before action is taken. Because of these problems, the observation of traffic conflicts has been advocated as an alternative or complementary approach to analyze traffic safety from a somewhat broader perspective than accident statistics alone (Brown and Sayed, 1993; Sayed *et al.*, 1994; Brown, 1994). The traffic conflict technique involves observing, recording and evaluating the frequency and severity of traffic conflicts at an intersection by a team of trained observers. The technique therefore provides a means for the analysts to immediately observe and evaluate unsafe driving maneuvers at an intersection, and to investigate the relationship between such maneuvers and the road characteristics.

This paper describes the application of the traffic conflict technique to the estimation of safety at intersections. It includes an overview of the establishment of traffic conflict standards at signalized and unsignalized intersections and the development of models which relate traffic conflicts to traffic volumes and accidents. In addition, the paper presents a case study which demonstrates the usefulness of the traffic conflict technique for analyzing the safety of intersections.

THE TRAFFIC CONFLICT TECHNIQUE

The concept of traffic conflicts was first proposed by Perkins and Harris (1967) as an alternative to accident data, which in many cases are scarce, unreliable, or unsatisfactory. Their objective was to define traffic events or incidences that occur frequently, can be clearly observed, and are related to accidents. They defined a traffic conflict as any potential accident situation leading to the occurrence of evasive actions such as braking or swerving. This simple definition has since been refined to incorporate categories of vehicle maneuvers and measures of time and space between vehicles at the time of conflicts. An internationally accepted definition of a traffic conflict is "an observable situation in which two or more road users approach each other in space and time for such an extent that there is a risk of collision if their movements remain unchanged." (Amundson and Hyden, 1977).

A variety of observation methods have been developed to measure traffic conflicts. These can be classified into subjective and objective methods. Subjective methods include considerable judgment by the conflict observer and are criticized by several researchers (Hauer, 1978) because the grading of severity of the evasive action can vary greatly from one observer to another. Objective methods include a cardinal or ordinal time-proximity dimension in the severity scale. The most widely used measure is the time to collision (TTC) defined as "the time for two vehicles to collide if they continue at their present speed and on the same path" (Hayward, 1972). The value of the TTC is infinite if the vehicles are not on a collision course. If the vehicles are on a collision course, the value of the TTC is finite and decreases with time. The minimum TTC reached as the vehicles approach on the collision course is taken as the critical measurement in estimating conflict severity.

Traffic Conflict Surveys in British Columbia

In 1986, a Traffic Conflict Procedures Manual was prepared by the University of British Columbia (Brown and Chau, 1986) for the Insurance Corporation of British Columbia (ICBC). The manual summarized the body of knowledge related to traffic conflicts at the time, and presented a procedure to observe systematically and record conflicts at intersections. This manual formalized naming conventions for conflict types, the most common of which are rear-end, left-turn opposing, crossing, left-turn crossing, right-turn, weaving and pedestrian. The manual also presented guidelines for conflict observer training requirements. Since 1989, ICBC has been providing funding for studies which analyze conditions at intersections where traffic safety is perceived to be a concern. The purposes of the studies are to investigate the factors contributing to unsafe conditions and to identify potential mitigating measures. The studies include a review of intersection geometry, capacity, accident history, and conflict characteristics based on conflict surveys conducted according to the procedures of the 1986 Manual. These studies have been conducted as part of ICBC's Road Improvement Programs in partnership with municipalities throughout

British Columbia, as well as the Ministry of Transportation and Highways.

By the end of 1996, conflict surveys had been completed at 94 intersections throughout British Columbia. This allowed for the establishment of traffic conflict standards, which can be used to evaluate relatively the frequency and severity of conflicts at various locations. A summary of some of the important aspects of the traffic conflict procedures, including measures of conflicts frequency and severity, follows.

Traffic Conflicts Observation and Measurement

At each study intersection, traffic conflicts are observed for two days, with 8 h of observation per day. Typically, two trained observers are stationed at strategic intersection observation locations for the 16 h of observation. The hours of observation are distributed as follows: morning period: 0700 to 1000 hours; noon period: 1100 to 1300 hours; and afternoon period: 1500 to 1800 hours. The severity of traffic conflicts is determined by the sum of two scores: the time to collision or TTC score and the risk of collision or ROC score (Table I). The ROC is a subjective measure of the seriousness of the observed conflict and is dependent on the perceived control that the driver has over the conflict situation, the severity of the evasive maneuver and the presence of other road users or constricting factors which limit the driver's response options. The ROC score is independent of the TTC score; however, conflicts with a high TTC score will typically, but not necessarily, have a high ROC score.

The sum of the TTC and ROC scores gives the overall severity score, which ranges between 2 and 6, with the higher values denoting high risk conflict situations. The midpoint of the composite scale registers the critical event, corresponding to a TTC of 1.5 s or less with a moderate ROC. Reliability tests of the observation method gave 77% accuracy with a 95% level of confidence, with an 85% accuracy for assessing the

TABLE I TTC and ROC scores

TTC and ROC scores	*Time to collision (TTC) (s)*	*Risk of collision (ROC)*
1	1.6–2.0	Low risk
2	1.0–1.5	Moderate risk
3	0.0–0.9	High risk

correct TTC. In addition, in a study of 13 intersections to test the validity of a TTC = 1.5 s or less for a measure of safety (as defined by the number of accidents), it was found that at eight of 11 intersections conflicts are significantly correlated with accidents at the 95% level of confidence with $R^2 \geq 0.64$ with three intersections having $R^2 \geq 0.81$ (Brown, 1994).

TRAFFIC CONFLICT STANDARDS AT INTERSECTIONS

Traffic conflict standards were developed for both conflict frequency and severity using the results of the 94 conflict surveys. The intersections were classified by traffic control type (signalized and unsignalized) and by area type (urban, suburban and rural). Table II provides a summary of the characteristics of the intersections included in the study. Conflict characteristics are typically different for signalized and unsignalized intersections. For example, crossing and left-turn crossing conflicts are usually the most common conflict types at unsignalized intersections, while rear-end and left-turn opposing conflicts are the most frequent conflict types at signalized intersections. As well, conflict causes are significantly different at urban and suburban locations. Congestion is typically a cause of conflicts at urban locations; speeding and intersection inconspicuity are typical conflict causes at suburban locations.

Cumulative distributions for various traffic conflict measures were developed. These measures include:

1. average hourly conflict (AHC): defined as the total number of observed conflicts at an intersection divided by the number of observation hours;
2. average hourly 4+ conflict (AHC 4+): defined as the total number of observed severe conflicts (conflicts with a total severity score of 4 or greater) divided by the number of observation hours;

TABLE II Summary of the characteristics of the study intersections

Traffic control	*Area type*			
	Urban	*Suburban*	*Rural*	*Total*
Signalized	13	39	0	52
Unsignalized	0	40	2	42
Total	13	79	2	94

3. AHC/PEV, where PEV is the square root of the product of the hourly entering volumes in thousands. For example, if the average hourly volumes of the major and minor roads are 500 and 800 veh/h respectively, then PEV = $\sqrt{0.5 \times 0.8} = 0.63$; and
4. AHC 4+/PEV.

For this analysis, all conflict types were combined and treated as an aggregate. Separate cumulative distributions were also developed (when possible) for different area types. Tables III and IV show the mean, variance, 90th percentile and 95th percentile of these distributions for signalized and unsignalized intersections. The 90th and 95th percentiles are considered abnormally high values which can be used as guidelines when evaluating the conflict risk at intersections.

In addition, an intersection conflict index (ICI) was established as shown in Figs. 1–4 for signalized and unsignalized intersections.

TABLE III Conflict standards for signalized intersections

Conflict measure	*Urban*				*Suburban*				*All signalized*			
	$\bar{X}$	σ^2	90%	95%	$\bar{X}$	σ^2	90%	95%	$\bar{X}$	σ^2	90%	95%
AHC	8.41	6.76	10.61	10.93	2.85	1.82	4.50	5.30	4.24	8.88	9.67	10.36
ARC 4+	2.24	0.79	3.51	3.70	0.72	0.24	1.32	1.84	1.12	0.83	2.35	2.89
AHC/PEV	4.38	1.42	5.88	6.03	2.46	1.14	3.61	3.73	2.94	1.90	4.90	5.87
AHC 4+/PEV	1.11	0.05	1.38	1.41	0.63	0.13	1.11	1.17	0.76	0.15	1.22	1.38

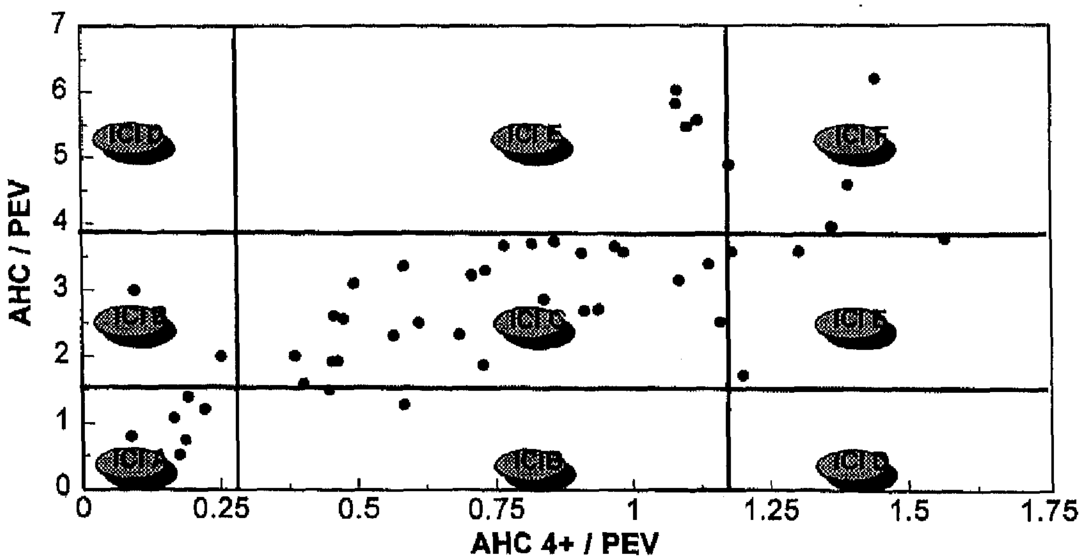

FIGURE 1 Intersection conflict index (ICI) for all signalized intersections.

TABLE IV Conflict standards for all unsignalized intersections*

Conflict measure	$\bar{X}$	σ^2	*90th percentile*	*95th percentile*
AHC	2.17	2.67	3.87	4.74
AHC 4+	0.66	0.29	1.49	1.77
AHC/PEV	5.21	13.60	8.93	10.70
AHC 4+/PEV	1.57	1.80	3.21	3.91

*Standards were not established for different area types because of insufficient data.

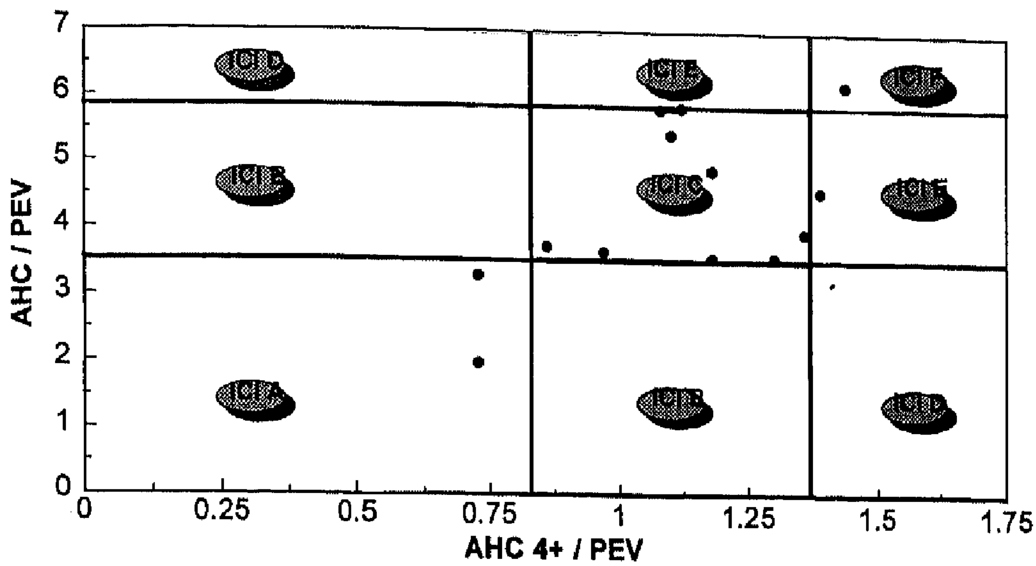

FIGURE 2 Intersection conflict index (ICI) for urban signalized intersections.

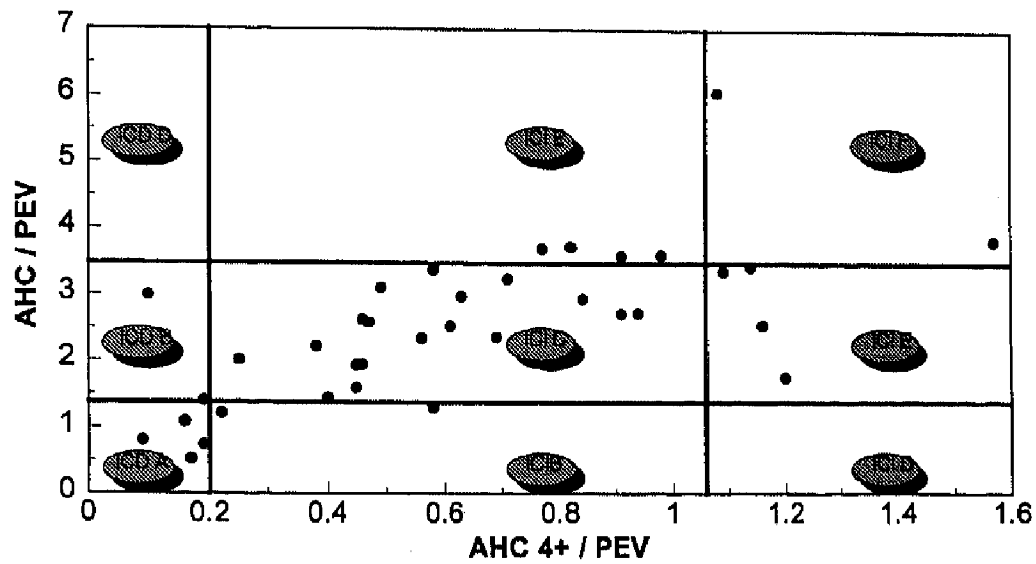

FIGURE 3 Intersection conflict index (ICI) for suburban signalized intersections.

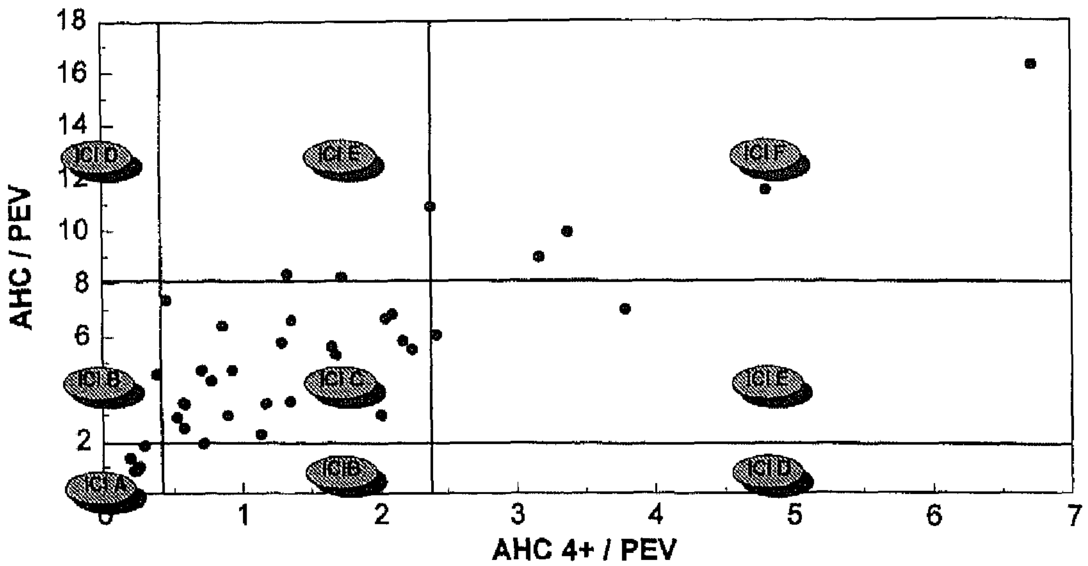

FIGURE 4 Intersection conflict index (ICI) for unsignalized intersections.

TABLE V Risk associated with intersection conflict index

Intersection conflict index (ICI)	*Conflict risk*
A	Negligible
B	Low
C	Moderate
D	Moderate to high
E	High
F	Extreme

The ICI regions were determined using the 15th percentile and 85th percentile of the (AHC/PEV) and the (AHC 4+/PEV) ratios. Similar to the Level of Service measure for capacity, the ICI is intended to summarize the conflict risk at an intersection, and it ranges between A (low frequency and low severity) and F (very high frequency and severity). The ICI therefore provides an indication regarding the relative risk of being involved in a conflict at an intersection. Table V provides the relative average conflict risk associated with each ICI.

CONFLICT PREDICTION MODELS

Several researchers have investigated the relationship between traffic conflicts and volumes. Spicer *et al.* (1979) found that the total number of traffic conflicts is proportional to the square root of the product of the conflicting volumes. Salman and Al-Maita (1995) investigated the relationship between traffic conflicts and two traffic volume measures: the sum of the volumes and the square root of the product of the volumes generating the conflicts. Both measures correlated well with traffic conflicts with the square root of the product of the volumes giving a higher correlation.

For this study, the relationships between the average hourly conflicts and the average hourly "4+" conflicts and the square root of the product of the major and minor road volumes (PEV) were investigated. The results are shown in Table VI for signalized and unsignalized intersections. For signalized intersections, models were developed which predict conflicts from traffic volume only (models 1 and 2) and enhanced models were also developed which predict conflicts from traffic volume and area-type (models 5 and 6). Examining first the models which predict conflicts using traffic volume only (models 1–4), the results indicate that the signalized intersection models explain 68% of the total variation in AHC and AHC 4+ while the unsignalized intersection models explain 69% and 65% of the variation. The results support the findings of Spicer *et al.* (1979) and Salman and Al-Maita (1995) which indicated that the total number of traffic conflicts is proportional to the square root of the product of the conflicting volumes.

Given that the signalized intersection group included both urban and suburban intersections which differ significantly in traffic conflict characteristics (Table III), a variable, AT, which represents area type, was included in models 1 and 2. The results (models 5 and 6) are shown in Table VI. As shown in the table, the R^2 values were significantly improved to 0.79 and 0.73 respectively.

TABLE VI Models for traffic conflicts and volumes

Model	*Category*	R^2
1: AHC = −1.04 + 3.61 PEV	Signalized	0.68*
2: AHC4+ = −0.40 + 1.08 PEV		0.68*
3: AHC = −0.50 + 6.15 PEV	Unsignalized	0.69*
4: AHC4+ = −0.21 + 1.75 PEV		0.65*
5: AHC = 5.58 + 2.48 PEV −2.82 AT	Signalized	0.79*
6: AHC4+ = 0.84 + 0.87 PEV −0.54 AT		0.73*

AT = area type (1 for urban and 2 for suburban).
*Significant at $\alpha = 0.001$.

Applications

The models shown in Table VI can be used in safety forecasting through estimating the expected number of conflicts. For example, assume that a proposed unsignalized intersection is expected to carry average hourly volumes of 900 and 200 veh/h for the major and minor roads respectively. Then using model 3 from Table VI, the predicted average hourly conflicts for this intersection is 2.11. The variance of the difference between the predicted and actual AHC can be estimated as

$$\mathrm{var}[\mathrm{AHC}_{\mathrm{predicted}} - \mathrm{AHC}_{\mathrm{actual}}] = s_{\mathrm{d}}^2\left(1 + \frac{1}{n}\right) + s_{\mathrm{a}}^2(x_i - \bar{x})^2 \qquad (1)$$

where s_{d} is the standard error of the AHC estimate and s_{a} the standard error of the coefficient for the variable x (as obtained from the regression analysis).

Alternatively, the variance in Eq. (1) can be calculated as

$$\mathrm{var}[\mathrm{AHC}_{\mathrm{predicted}} - \mathrm{AHC}_{\mathrm{actual}}] = A + B \times \mathrm{PEV}^2 - C \times \mathrm{PEV} + D \quad (2)$$

where A, B, C, D are constants associated with each model and given in Table VII.

Using Eq. (2), the variance is 0.83. The final conflict estimate is 2.11 ± 1.79 at the 95% confidence interval level.

Relationships Between Traffic Conflicts and Accidents

Linear regression analysis was used to model the relationship between traffic conflicts (both AHC and AHC 4+) and accidents. The accident

TABLE VII Constants for calculating the variance of predicted conflicts

Model	*Category*	*Constant A*	*Constant B*	*Constant C*	*Constant D*
1	Signalized (AHC)	2.85	0.14	0.38	0.0
2	Signalized (AHC 4+)	0.23	0.01	0.04	0.0
3	Unsignalized (AHC)	0.91	0.49	0.39	0.0
4	Unsignalized (AHC 4+)	0.10	0.05	0.04	0.0
5	Signalized (AHC with area type)	2.00	0.15	0.41	0.21* 0.02**
6	Signalized (AHC 4+ with area type)	0.21	0.02	0.04	0.02* 0.002**

*Area type 1: urban; **Area type 2: suburban.

TABLE VIII Models for accident and conflicts

Model	*Category*	R^2
7: Acc/yr = 4.98 + 5.02 AHC	Signalized	0.77*
8: Acc/yr = 8.69 + 14.23 (AHC 4+)		0.70*
9: Acc/yr = 2.69 + 0.69 AHC	Unsignalized	0.20
10: Acc/yr = 3.52 + 1.61 (AHC 4+)		0.11

*Significant at $\alpha = 0.001$.

TABLE IX Constants for calculating the variance of predicted accidents

Model	*Category*	*Constant A*	*Constant B*	*Constant C*
7	Signalized	71.401	0.176	1.462
8		87.210	2.093	4.897

data included all reported accidents at a given location for a three year period. The results of the analysis are shown in Table VIII. As shown in the table, the signalized intersection AHC and AHC 4+ models explain 77% and 70% of the variation in accidents, respectively, while the unsignalized intersection AHC and AHC 4+ models explain only 20% and 11% of the variation. The low correlation for unsignalized intersection models may be related to the quality of accident data and the randomness inherent in the low accident frequency.

As described earlier, the models in Table VIII can be used in safety forecasting through estimating the expected number of accidents per year. The accuracy of this estimate is represented by the variance which is calculated as

$$\text{var(Acc/yr)} = A + B \times (\text{AHC or AHC4+})^2 - C \times (\text{AHC or AHC4+}) \quad (3)$$

where A, B, C are constants associated with models 7 and 8 and are given in Table IX.

CONFLICT CAUSES AND INTERPRETATION

The results of the traffic conflict analysis should be used in conjunction with the review of the intersection's geometric, traffic and accident history characteristics. The results of the traffic conflict analysis are therefore part of a systematic framework for analyzing intersection deficiencies and generating solutions. This integrated methodology ensures a well-rounded and thorough evaluation of traffic operations.

The results of the traffic conflict analysis may support the accident analysis, supplement lacking or inaccurate accident data, and emphasize the intersection deficiencies. The identification of traffic conflict causes greatly enhances the problem solving process. A case study will be presented as an example on the usefulness of the traffic conflict analysis.

Case Study

This case study showed that when accident data are unavailable or of questionable accuracy, traffic conflict data can be used to identify traffic operation deficiencies. The intersection of Highway 97 and Oyama Road/Irvine Road is an unsignalized intersection in the community of Oyama in the Okanagan region of British Columbia. Highway 97 is the major roadway, providing two through lanes, and right and left-turn lanes in each direction. Oyama Road and Irvine Road are local roads, providing one through lane and one left-turn lane in each direction. There is a marked zebra crosswalk across Highway 97 at the intersection.

Analysis of the available reported accidents failed to reveal any significant collision patterns, as there were only six collisions over three years. The accidents analysis was therefore unable to identify any traffic operation deficiencies. The collision diagram is shown in Fig. 5.

A traffic conflict survey was conducted to identify the safety risks at the intersection. A total of 56 conflicts were recorded over two days, and revealed distinct spatial conflict patterns. The conflict diagram is shown in Fig. 6. The analysis showed that 29% of the conflicts were related to vehicles crossing Highway 97 from Oyama Road, and that 16% were related to pedestrians crossing Highway 97 on the marked crosswalk. The percentages of both crossing and pedestrian-related conflicts were higher than the average at other intersections. Further analysis showed that when considering only conflicts with a severity score of 4 or more, the percentage of crossing and pedestrian related conflicts increased to

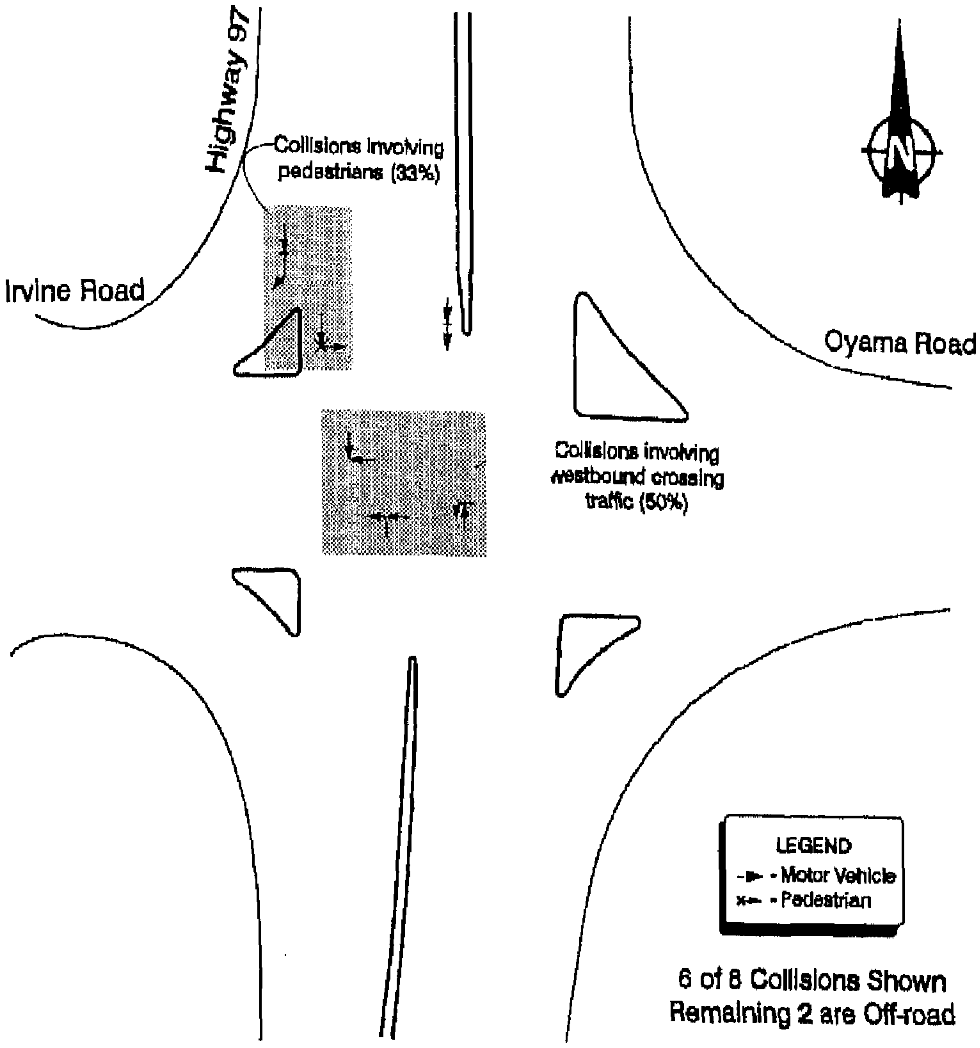

FIGURE 5 Case study collision diagram.

37% and 26% respectively. This provided a strong indication that the vehicles crossing Highway 97 from Oyama Road and the pedestrians crossing Highway 97 on the marked crosswalk created the greatest accident risk at the intersection.

Using the conflict data, the deficiencies at this intersection were identified as drivers on Highway 97 failing to anticipate the intersection or the crosswalk, and inadequate crossing gaps for minor street crossing traffic. The recommended improvement was to provide a traffic signal with associated warning flashers and pedestrian push-button activation. This option would improve the performance of the minor street and pedestrian movements, and reduce safety risks.

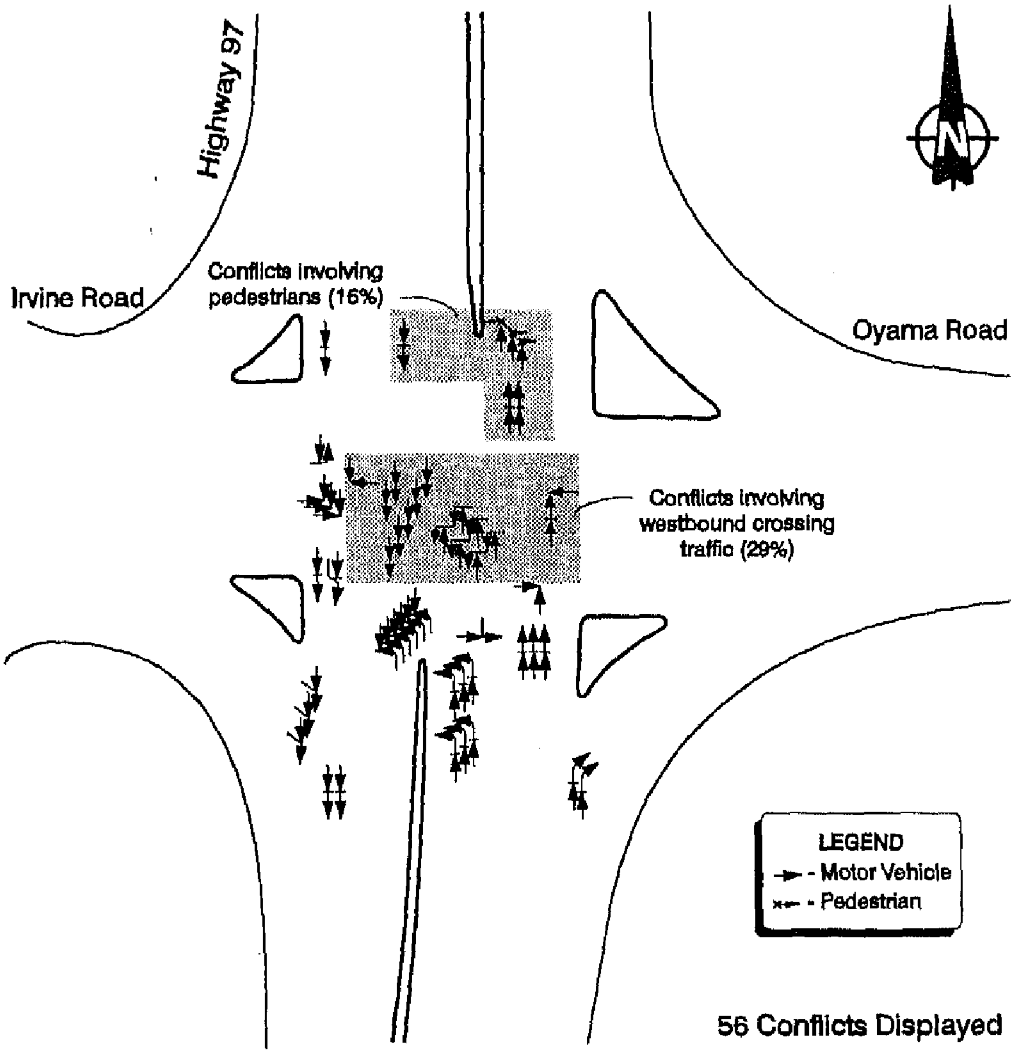

FIGURE 6 Case study conflict diagram.

CONCLUSION

Using data collected from 52 signalized and 42 unsignalized intersections throughout British Columbia, traffic conflict standards have been established. An intersection conflict index (ICI) was developed for each type of intersection by plotting AHC 4+/PEV against AHC/PEV. Six levels ranging from A to F, from low frequency and low severity to very high frequency and high severity respectively, were used in the ICI to summarize the intersection conflict risk. Linear models relating traffic volumes and conflicts were developed for both signalized and unsignalized intersections. The results indicated that both the average hourly conflicts and the average hourly 4+ conflicts correlated well with the square root of the product of the hourly entering volumes in thousands, PEV. The relationships between accidents and conflicts (AHC and AHC 4+) for both signalized and unsignalized intersections were also investigated. Strong relationships were found between accidents and AHC and AHC 4+ for signalized intersection models while unsignalized models displayed very weak relationships. A case study showed that when collision data are unavailable or of questionable accuracy, traffic conflict data can be used to identify traffic operation deficiencies.

It is recommended that the conflict standards and models developed in this study be updated as more conflict surveys are conducted. In addition, further investigation can be pursued in determining the relationships between the specific conflict types and the traffic volumes which generate these types of conflicts.

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