It should be emphasized that all the above results are for the whole Singapore area. Furthermore, the observed changes cannot--and should not--be attributed solely to ALS. Other factors, such as the economic slowdown during 1975, may have caused the observed changes. The point to note, however, is that any anticipated effects of a major change in system supply or policy measures should be analyzed and evaluated within the context of total travel, since the effects may spread to other, possibly unforeseen, parts of travel behavior. To name just one example: The principal justification for improving a road network is the economic benefits of saved travel time by its users. However, since the saved times are often traded off for more travel, forecasts of future travel are found to be underestimates. Thus, analysis of the possible effects of a change in travel conditions should also cover their possible propagation through the whole travel system.

The measurements relating to total daily travel, which are required to monitor travel behavior, either once a year or before and after a major change in travel conditions, can be restricted to a small sample. For instance, travel patterns of one-day cross-sectional data appear to stabilize for groups of travelers numbering 25 or more. Thus, depending on the number of desired stratifications, a sample of several hundred households may often be large enough to provide all required data. In the case of minor changes in travel conditions, measurements of travel behavior could be limited to the households of the travelers directly affected by the program.

It is recommended, therefore, that more attention be given to such small--but continuous--home-interview surveys that, coupled with the standard periodic traffic counts, can provide a reliable basis for the evaluation of such changes in travel behavior as those that result from the introduction of HOV-priority programs.

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Traffic Conflicts Techniques for Use at Intersections

WILLIAM D. GLAUZ AND D. J. MIGLETZ

Field studies and analyses of observation of traffic conflicts at intersections are described. The field studies covered more than 24 sites and used 17 trained observers who applied a number of alternative operational definitions of traffic conflicts. The definitions that provide the best reliability, repeatability, and practicality are recommended. Initial estimates obtained of expected conflict rates as a function of type of intersection are also given.

Traffic accidents are the most direct measure of safety for a highway location. However, attempts to estimate the relative safety of a highway location are usually hampered by the problems of unreliable accident records and the time required to wait for adequate sample sizes. For these reasons, therefore, the Traffic Conflicts Technique (TCT) was developed in an attempt to objectively measure the accident potential of a highway location without having to wait for a suitable accident history to evolve. (Viewed simply, a traffic conflict is a traffic event involving the interaction of two vehicles in which one or both drivers may have to take an evasive action to avoid a collision.)

Most people who have even a fragmentary knowledge of the TCT believe they understand the basic concepts. However, among those who pursue it further, there is a great divergence of opinion, philosophically, about traffic conflict definitions. One school of thought (1) holds that a proper definition of a traffic conflict must ensure that every accident be preceded by a conflict. Although the use of traffic conflicts as accident surrogates is an appealing concept, it can lead to unrealistic data-collection requirements. Also, attempts to find strong correlations between conflicts and accidents have, for the most part, been either unfruitful or misleading for a number of reasons (2).

In the United States, it is more acceptable to view traffic conflicts as logical indicators of safety or operational problems, even if the relationship cannot yet be placed on sound statistical grounds. Obviously, it is desirable that operational definitions of traffic conflicts imply a relationship with safety, but other attributes are also necessary:

1. Safety-relatedness: At least in a conceptual sense, conflicts should be related to accidents.
2. Site-relatedness: Conflicts should be useful in diagnosing problem locations or measuring the effectiveness of a site improvement.
3. Reliability: The definition should provide minimum variation between different observers who record the same event.
4. Repeatability: The definition should result in an acceptable level of variation in repeated observations by the same observer at the same site under nominally identical conditions. This attribute has an important impact on determining meaningful sample sizes.
5. Practicality: Reliable, repeatable, safety-related, and site-related data should be obtainable in a reasonable time and at reasonable expense.

The research summarized here was a part of NCHRP Project 17-3 (3), which was directed toward the determination of operational definitions of traffic conflicts that best satisfy the last three of the attributes listed above. The first two attributes were considered only to the extent that the limited data permitted.

DEFINITIONS

If they are to be implemented widely in the United States, operational definitions must avoid or minimize the use of sophisticated equipment or painstaking measurements. They must be suitable for direct application by human observers. Therefore, operational definitions must encompass readily observable events.

To be observable, the traffic event must elicit an evasive maneuver (braking or swerving) by the offended driver. In this respect, the operational definitions are like those of the General Motors (GM) study (4,5). An intersection traffic conflict can be described, operationally, as a traffic event involving several distinct stages: One vehicle makes some sort of unusual or unexpected maneuver, a second vehicle is placed in jeopardy of a collision, the second vehicle reacts by braking or swerving, and the second vehicle then proceeds through the intersection. The last stage is necessary to convince the observer that the second vehicle was, indeed, responding to the offending maneuver and not, for example, to a traffic-control device.

Within this framework, a basic set of operational definitions can be stated that correspond to different types of instigating maneuvers. One type, called a left-turn, same-direction conflict, occurs when an instigating vehicle slows to make a left turn, thus placing a following, conflicted vehicle in jeopardy of a collision. The conflicted vehicle brakes or swerves, then continues through the intersection (see Figure 1). A total of 13 basic conflicts were defined as candidates to be field tested. These basic intersection conflicts are

1. Left turn, same direction;
2. Right turn, same direction;
3. Slow vehicle, same direction;
4. Lane change;
5. Opposing left turn;
6. Right-turn cross traffic, from right;
7. Left-turn cross traffic, from right;
8. Through cross traffic, from right;
9. Right-turn cross traffic, from left;
10. Left-turn cross traffic, from left;
11. Through cross traffic, from left;
12. Opposing right turn on red (during protected left-turn phase); and
13. Pedestrian.

Alternative operational definitions were also tested in the field to determine their value relative to these basic definitions. For each of the 13 basic types of conflicts, other more-restrictive or less-restrictive definitions were examined. For the first 3 conflicts listed above, the original GM work specified that the vehicles must be traveling as a pair in a car-following situation. In practice, however, some users prefer to include all situations in which a second vehicle brakes or swerves, even if it came on the leading vehicle several seconds later. The all-inclusive definitions include both paired-vehicle and non-paired-vehicle conflicts. For the other types of conflicts listed, the GM study suggested counting vehicles. An alternative terminology is suggested--the counting of opportunities.

The above descriptions identify 39 different operational definitions of traffic conflicts. All were used, except that pedestrian-related conflicts were so rare that they were not analyzed.

More-restrictive traffic conflicts were defined as those that exceed some threshold level of severity. Specifically, a conflict was said to be severe if the time-to-collision value was less than 1.5 s, as determined subjectively by trained observers. Time-to-collision value is defined as the time interval from when a conflicted vehicle reacts (brakes or swerves) until a collision (or a near miss) would have occurred had there been no reaction (6).

For each conflict type there can also be a traffic event called a secondary conflict that is comparable to the GM previous conflict. The secondary conflict involves an additional vehicle that is affected by the vehicle that slowed or swerved in response to an initial conflict situation.

The above conflict categories, plus others created by grouping or collapsing categories in the analysis process, yielded 62 conflict categories that were subjected to formal analysis. This does not include the severe conflicts, which were analyzed separately by hand.

FIELD STUDIES

Extensive field tests were conducted in the greater Kansas City metropolitan area during the summer of 1978 to obtain data on the candidate operational definitions of traffic conflicts. These tests employed observers without traffic experience who received a special two-week training program.

Experimental Plan

The basic experiment involved 24 intersections that had the descriptive parameters displayed in Table 1. This table also shows 4 additional sites used in a subsidiary experiment. Most of the sites were located in rural and suburban areas. Some were in areas zoned for business or industry but none in the central business district.

The basic experiment used trained observers who worked in pairs, alternately (every 0.5 h) viewing from opposing legs of the intersections. Each observer collected traffic conflicts and volume data at a specified site for half a day with a designated partner and then moved to another site for half a day to work with a different partner. A four-day, 40-h weekly schedule created a basic experimental phase of three weeks, during which each of 24 sites was observed for three mornings and three afternoons, and each observer worked with every other observer at least twice. Three phases were conducted, the results of which could be analyzed separately, compared, or combined.

Statistical Model

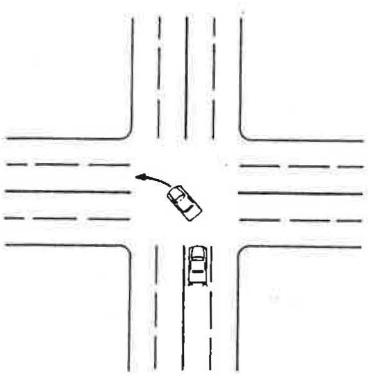
Mathematically, the variance σ_Y^2, obtained as a result of repeated short observations of the same type of conflict (Y) over a period of weeks at numerous sites by different persons and at different times of day on different days, can be assigned to the identifiable factors according to their numerical contributions to σ_Y^2. That is,

$$\sigma_Y^2 = \sigma_O^2 + \sigma_t^2 + \sigma_D^2 + \sigma_N^2 + \sigma_S^2 + \sigma_L^2 + \sigma_\ell^2 + \sigma_C^2 + \sigma_R^2 + \sigma_e^2 \qquad (1)$$

where

- σ_O^2 = observer variance (reliability)--the variation resulting from systematic biases between observers,
- σ_t^2 = the variance between the short observation intervals at a site,
- σ_D^2 = the variance between days of week at a site,
- σ_N^2 = the variance between three-leg and four-leg sites,
- σ_S^2 = the variance between low-speed and high-speed sites,
- σ_L^2 = the variance between two-lane and four-lane unsignalized intersections,
- σ_ℓ^2 = the variance between legs at a site,
- σ_C^2 = the variance between signalized and unsignalized four-lane intersections,
- σ_R^2 = the variance between replicate sites of nominally the same type (same speed, number of lanes, and traffic control), and
- σ_e^2 = residual variance, or error, that is the repeatability sought by the project (this is the variance of repeated observations by the same observer under theoretically identical conditions--same physical site, time of day, day of week, etc.).

Figure 1. Left-turn, same-direction conflict.



FIELD STUDY RESULTS

The analyses dealt with 4000 observer hours of conflict and volume counts, and the major results are presented here. More detailed tabulations and discussions may be found in the research report of Glauz and Migletz (3).

Severe Conflicts

A grand total of 104 severe conflicts at the 28 test sites were noted, an average of about 1 per 18 observer hours of observation. Six of these 104 were accidents. Chi-square analyses showed that there were no significant differences in the counts that were attributable to the factors characterizing the sites, nor were there any specific sites that had abnormally high or low severe-conflict counts.

Severe conflicts also showed no significant differences by day of week, and they were rather uniformly distributed throughout the morning and early afternoon hours. However, they were much more prevalent by midafternoon (2:30-3:00 p.m.) and peaked sharply in the late afternoon, as shown in Figure 2.

Severe conflicts were also examined to determine whether they were distributed among types in the same way as regular conflicts. For this purpose four groupings were used: rear-end or same-direction conflicts, opposing left-turn conflicts, cross-traffic-from-right conflicts, and cross-traffic-from-left conflicts. The analysis showed that the distributions of regular conflicts and severe conflicts were greatly different. Whereas about 83 percent of all conflicts were of the same-direction variety, only 55 percent of the severe ones were of this type. Instead, the severe conflicts were more likely to be of the cross-traffic or opposing left-turn variety.

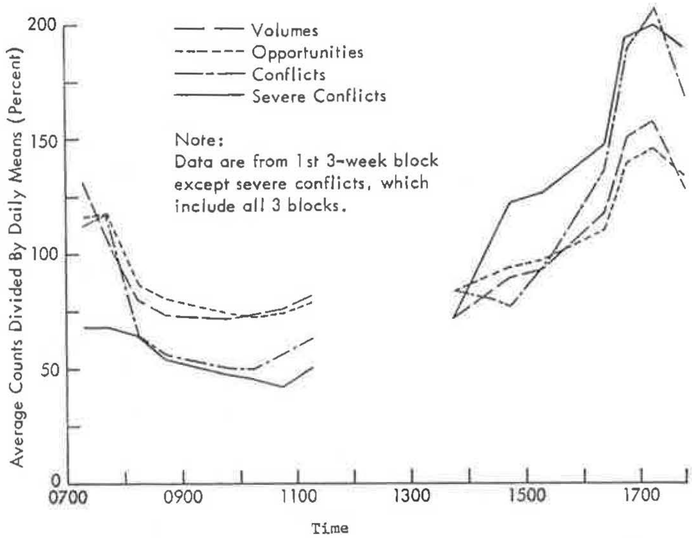
Analyses showed significant differences between observers; 4 of the 17 observers recorded essentially half (51 out of 104) of the severe conflicts. Thus, these traffic measures suffer from a lack of reliability, as well as from being infrequent and not site discriminating, and they are different in nature from other (normal) conflicts.

Table 1. Experimental design framework.

			High Speed[a]		Low Speed[b]	
Experiment	Lanes	Signalization	Four-Way	Three-Way	Four-Way	Three-Way
Basic	4	No	X	X	X	X
	4	Yes	X	X	X	X
	2	No	X	X	X	X
Subsidiary	2	Yes	X	–	X	–

Note: Each X represents two physical sites, each with two legs or approaches being observed.
[a]High-speed intersection = speed limit ≥ 40 mph.
[b]Low speed intersection = speed limit < 40 mph.

Figure 2. Time-of-day effects.



Rarely Observed Conflict Categories

Below are listed the conflict categories routinely recorded that should be dropped as useful concepts because they are so rare as to be impractical observational measures.

Conflict Type	Observer Hours per Occurrence
Right-turn-on-red secondary conflict	None observed
Right-turn-from-left secondary conflict	250.0
Lane-change secondary conflict	62.5
Right-turn-from-left conflict	33.3
Cross-traffic-from-left secondary conflict	23.8
Cross-traffic-from-right secondary conflict	15.9
Opposing left-turn secondary conflict	13.5
Right-turn-from-right secondary conflict	11.6
Left-turn-from-right secondary conflict	11.2
Right-turn-on-red conflict	9.4
Left-turn-from-left secondary conflict	8.3
Lane-change conflict	6.4
Right-turn-from-left opportunity	4.1
Right-turn-on-red opportunity	3.0

Essentially, the tabulated conflicts each occurred (at most) only about once for every eight observer hours of observation, equivalent to about two workdays. The right-turn-from-left opportunity and the right-turn-on-red opportunity were observed somewhat more frequently, but the interobserver variance was unusually high. The majority of the counts were obtained (probably erroneously) by just a few of the observers. The definition of these events is apparently difficult, conceptually.

Reliability

Reliability is the degree to which different observers record identical results when they observe the same traffic events. It is quantified by the interobserver variance σ_O^2. These variances were calculated separately for each of the first two three-week phases and compared. For all practical purposes, they did not differ between phases, i.e., no noticeable differential change between observers occurred as a result of long-term learning or practice effects; the two-week training program had effectively completed this process.

Some of the interobserver variances for one of these phases are given in Table 2 for selected conflict categories. In general, σ_O^2 represents only a small part of the total variation in conflict counts (typically, a few percent); other factors appear to be more important. A few exceptions are notable. The right-turn, same-direction conflicts had poor reliability, as indicated by comparatively large σ_O^2 (more than 10 percent of the total variance), and so did left-turn, same-direction, and paired-vehicle conflicts and all rear-end, paired-vehicle conflicts (not shown). Several other rear-end conflict types had reliabilities nearly as poor, as did some cross-traffic opportunities.

The coefficients of variation ranged from 9 percent to 109 percent; nearly all of them were under 50 percent. The worst was right-turn-on-red opportunities, whose high coefficient of variation (CV) indicates lack of uniform understanding among the observers. All paired-vehicle conflict categories also had high CVs, indicating that observers had difficulties with the paired-vehicle concept. This is clearly illustrated below:

Conflict Category	Coefficient of Variation (σ_O/mean) (%)
Left turn, same direction	
Paired vehicle	67.63
Not paired	35.87
Total	21.19
Right turn, same direction	
Paired vehicle	42.96
Not paired	101.82
Total	19.50
Slow vehicle	
Paired vehicle	54.25
Not paired	34.16
Total	41.20

The overall reliabilities, particularly for the left- and right-turn categories, are very good, but

Table 2. Illustrative conflict-count variances for the first three weeks.

Conflict Category	Mean No. of Conflicts Each 15 min	Conflict Count Variance[a] (σ_y^2)	Residual Variance[b] (σ_e^2)	Observer Variance[c] (σ_o^2)
Left turn, same direction	1.1191	3.3044	2.7847	0.1611
Right turn, same direction	0.5232	1.0687	0.9023	0.2838
Slow vehicle	0.2913	0.5319	0.5143	0.0099
Opposing left turn	0.2435	0.4497	0.4041	0.0035
Right turn from right	0.1664	0.2569	0.2369	0.0069
Cross traffic from right	0.1226	0.1374	0.1281	0.0017
Left turn from right	0.1770	0.3407	0.3108	0.0060
Left turn from left	0.2249	0.4003	0.3580	0.0085
Cross traffic from left	0.0984	0.1104	0.1067	0.0009[d]
All same direction	4.5939	30.6617	22.8934	1.3049
All cross traffic from left	0.2494	0.5393	0.4816	0.0088
All cross traffic from right	0.4030	0.9195	0.7882	0.0380
All conflicts	5.2827	36.3247	26.2166	1.8287

[a]Total variance in the conflict counts.
[b]Repeatability measure (variance not attributable to observers, time of day, site, day of week, or other measured parameter).
[c]Reliability measure.
[d]Not statistically significant at 0.95 confidence level.

they are much poorer (high CV) when subdivided into paired-vehicle and not-paired categories. The table shows a similar tendency for the slow-vehicle categories, but here even the total reliability is not good. Clearly, the observers were not uniform in separating driver responses to slow vehicles from, say, responses to traffic controls or, perhaps, secondary conflicts.

Repeatability

The ability of an observer to count conflicts uniformly at a given site under "identical" conditions is called the repeatability. Conceptually, it could be measured by staging sequences of traffic events to occur repeatedly. A more practical approach might be to videotape such events and review them repetitively in the office or laboratory. However, this procedure lacks realism and may not lead to results easily translated into field practice.

In reality, the observer should view actual traffic many times under conditions as nearly alike as possible. This is, in effect, what we did. The factors that might introduce variability into conflict counts, such as time of day and day of week, were identified and accounted for, as described previously. What remained (the residual variance, σ_e^2) was the result of two effects:

1. The true or theoretical repeatability that might be obtained by a hypothetical experiment as described above and
2. The inherent variability in real conflicts as traffic events, totally analogous to the well-known variance observed in repeated traffic counts.

The combination of these two effects is the practical repeatability--the result that can be expected in real-world, repeated counts.

Repeatabilities were found to improve somewhat (smaller σ_e^2) in the second phase, suggesting that as a group the observers became more repeatable with additional experience. Also, mean conflict counts tended to decrease somewhat, especially for the same-direction conflict categories.

Nevertheless, the residual variances were generally large and represented the major contributors to the total variances in conflict counts--typically, 50-90 percent or more. This probably means that the inherent variability in conflict-event rates is quite large. It is not conceivable that trained observers count so erratically.

This finding can be put in better perspective by comparing the ratios (σ^2/μ) for various traffic events. For accidents, which most believe to have approximately a Poisson distribution, $\sigma^2/\mu = 1$. For the 15-min conflict counts obtained in this project, σ^2/μ is in the range of 1.5-3.5, depending on the type examined (rear end, opposing left turn, etc.). For conflict opportunities the results indicated a range of 3-16 or more for the various types. Finally, analysis of scattergrams and the like presented in the Highway Capacity Manual (7) and the Traffic Engineering Handbook (8) yields values from 9 to 90 percent for σ^2/μ for traffic volume counts.

Coefficients of variation of the repeatability measure for 15-min counts ranged from 73 to 685 percent. The outstandingly bad conflict category, from a repeatability viewpoint, is the right-turn-on-red opportunity; cross-traffic conflict types and opposing left-turn conflicts had CVs of more than 200 percent for 15-min counts.

Observation Periods Required

CVs for repeatability decrease as the observation period increases, according to $\sqrt{n}$. That is, use of a 1-h count instead of a 15-min count would reduce the CV by half, and use of 4-h data sets would yield CVs only one-fourth as large. Thus, the precision of an estimated mean count increases as longer count periods are used.

If one wants to estimate, say, the mean number of hourly traffic conflicts at an intersection within a range of $\pm$ p percent with confidence $1 - \alpha$, then the number of hours required is

$$n = (100\, t/p)^2 \sigma_e^2/\bar{Y}^2 \qquad (2)$$

where

Y = hourly mean value,
σ_e^2 = hourly variance, and
t = statistic from the normal distribution defined by α, as tabulated in most statistics texts, for example, t = 2.58, 1.96, 1.65, and 1.28 for α = 0.01, 0.05, 0.10, and 0.20, respectively (for large n).

Applications of this principle are demonstrated in Table 3. For same-direction conflicts, the requirements can be met in about a day of observation, assuming the observer is actively counting conflicts about half the time. For opposing left-turn and summary cross-traffic categories, about one week would be required; nearly two weeks are needed for the individual cross-traffic categories for the conditions stated (± 50 percent with α = 0.10). Use of four times as much data would double all the precisions. However, as described next, some categories (especially cross traffic and opposing left turn) are very site dependent; less observation would be required at sites that have higher-than-average counts.

Site Characteristics

Below are some observations made on site characteristics.

1. Speed--Speed limit did not affect cross-traffic or opposing left-turn conflicts, but there was a tendency for more rear-end conflicts (except to turn right) and conflict opportunities on high-speed routes.
2. Three-way versus four-way intersections--More opportunities and conflicts occurred at three-way intersections, geometrics permitting.
3. Signalized versus unsignalized, four-lane intersections--At signalized intersections there were more rear-end conflicts of all types, except in conjunction with right turns; more opposing left-turn conflicts and opportunities; and fewer cross-traffic conflicts and opportunities.
4. Two-lane versus four-lane, unsignalized intersections--More rear-end conflicts of all types and fewer cross-traffic conflicts were observed at two-lane intersections; no highly significant differences were found in opposing left-turn conflicts or in any types of conflict opportunities.
5. Two-lane versus four-lane, signalized intersections (based on extra-site data)--No significant differences of any kind were noted.

Table 3. Illustrative observation requirements.

Conflict Category	Mean Hourly Count	Hours of Observation
Left turn, same direction	7.14	4.6
Right turn, same direction	4.89	5.1
Slow vehicle	3.21	5.9
Opposing left turn	0.77	21.6
Right turn from right	0.71	23.9
Cross traffic from right	0.31	39.3
Left turn from right	0.59	24.5
Left turn from left	0.78	18.1
Cross traffic from left	0.39	30.0
All same direction	15.48	3.4
All cross traffic from left	0.82	20.0
All cross traffic from right	1.45	14.8

Note: Hours of observation = hours of data required to estimate mean hourly count within ± 50 percent with 90 percent confidence.

Traffic Conflict Rates

In order to calculate conflict rates, several candidate normalizing volumes were examined, such as total intersection volume, main-line volume, cross-traffic volume, and left-turning volume. The best agreement was achieved with the main-line volume.

Analyses of variance were conducted of various average conflict-count rates by using main-line volume to determine significant site characteristics. Average conflict rates by type of site, as well as the standard errors, are shown in Table 4.

Typical rates for cross-traffic conflicts ranged from 0.18 to 4.43 per 1000 main-line vehicles, depending on the type of site. The only significant factor, however, is the presence or absence of signalization. Other things being equal, signalized intersections experienced only about one-tenth as many cross-traffic conflicts as did unsignalized intersections.

The most significant difference between sites for

Table 4. Average conflicts per 1000 main-line vehicles.

Intersection Type	High Speed Four-Way	High Speed Three-Way	Low Speed Four-Way	Low Speed Three-Way
Cross-Traffic Conflicts (S_e = 0.75)				
Four-lane, unsignalized	4.43	2.96	2.98	2.74
Four-lane, signalized	0.48	0.18	0.56	0.26
Two-Lane, unsignalized	3.78	3.98	4.02	3.53
Same-Direction Conflicts (S_e = 4.07)				
Four-Lane, unsignalized	15.57	12.78	16.65	12.45
Four-lane, signalized	12.14	14.24	21.34	13.92
Two-Lane, unsignalized	53.85	35.62	33.62	28.52
Opposing Left-Turn and Same-Direction Left-Turn Conflicts (S_e = 4.18)				
Four-lane, unsignalized	5.23	8.13	8.26	0.96
Four-lane, signalized	5.57	7.51	14.70	6.38
Two-lane, unsignalized	31.82	21.13	12.69	7.72
All Conflict Opportunities (S_e = 82.4)				
Four-lane, unsignalized	315.8	295.6	107.3	119.5
Four-lane, signalized	69.4	33.2	74.6	81.0
Two-lane, unsignalized	196.7	271.0	258.5	160.5
All Conflicts (S_e = 5.45)				
Four-lane, unsignalized	15.97	13.45	18.04	13.92
Four-lane, signalized	11.71	13.67	12.11	11.55
Two-lane, unsignalized	48.50	31.87	29.60	27.71

same-direction conflict rates resulted from the number of lanes on the main-line approach: Two-lane roads experienced nearly three times as many as four-lane roads. It is also noteworthy that fewer same-direction conflicts are seen at three-way intersections than at four-way intersections, other things being equal.

Figure 3. Opposing left-turn accidents and conflicts.

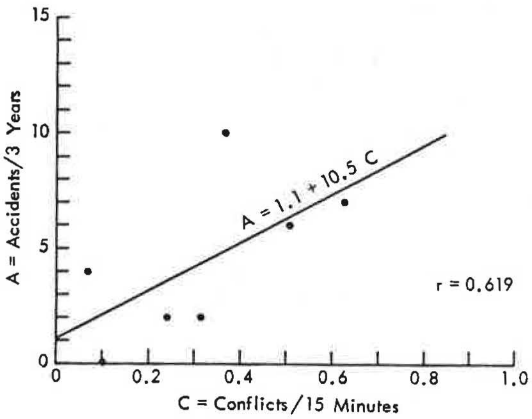


Figure 4. Cross-traffic accidents and conflicts.

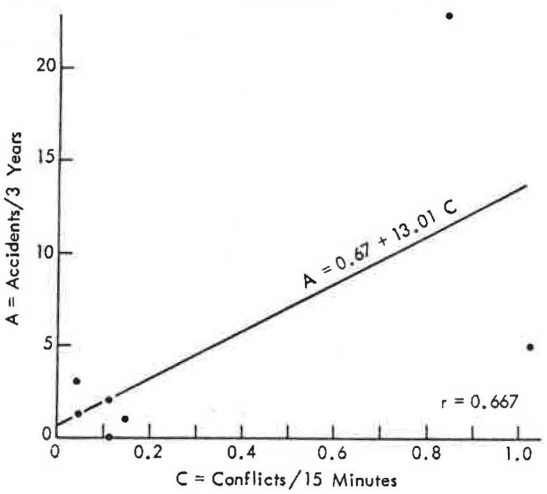
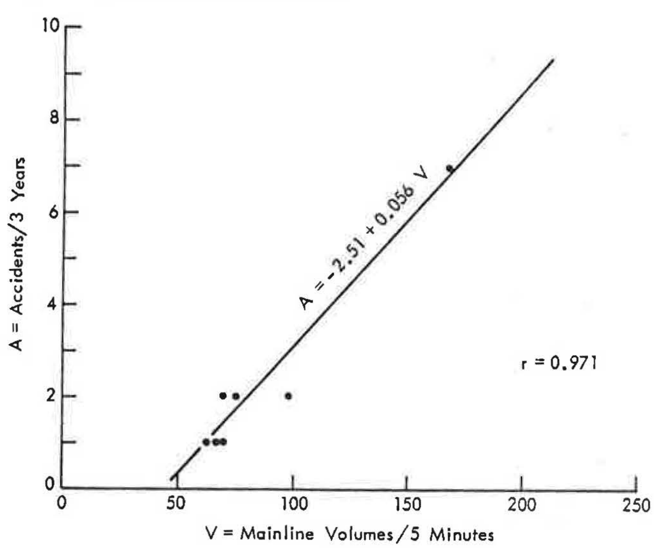


Figure 5. Same-direction accidents and volumes.



The conflict rates related to left-turn movements were significantly higher on two-lane roads. It is also noteworthy, although not statistically significant, that so few conflicts per 1000 vehicles were seen at low-speed, three-way, four-lane unsignalized intersections.

There were significantly fewer total conflict opportunities at signalized intersections than at others, as expected. The lack of other significant findings results in part from the very large standard error (S_e), which is about half of the overall average of 165.2 conflict opportunities per 1000 main-line vehicles. Generally, total conflicts exhibited the same sort of results as did same-direction conflicts.

Day-of-Week and Time-of-Day Effects

There were no clear-cut, uniform differences in conflict counts by day of week. Mondays may have experienced a few more conflicts of some types than did other weekdays, and Fridays may have experienced more conflict opportunities of some types.

Time-of-day effects for severe conflicts were described earlier and depicted in Figure 2. Whereas severe conflicts exhibit only an afternoon peak, both morning and afternoon peaks exist for volumes and opportunities. Other traffic conflicts tend to have both morning and afternoon peaks, but the latter peak is far more pronounced. The observation of higher conflict rates in the afternoon is in agreement with general accident experience, and both imply that driving habits, on the average, deteriorate late in the day.

Accident Relationships

Limited accident data for the intersections used in this study provided some insight into conflict-accident relationships. Overall correlation coefficients between total accidents over a three-year period and several categories of conflicts at the experimental sites were relatively meaningless. Total traffic volumes correlated as well as anything.

When accidents of certain types were compared with conflicts of analogous types, much better relationships were obtained. Opposing left-turn accidents and cross-traffic accidents, particularly, yielded good (significant) correlations with analogous conflicts (see Figures 3 and 4).

Comparisons between accidents and analogous conflict opportunities were mostly unproductive. Most correlation coefficients were essentially zero. The exception was rear-end accidents, which had a high correlation coefficient with main-line volumes (0.971), based on very limited data (see Figure 5).

DISCUSSION

Uses of Traffic Conflicts

To apply the TCT is somewhat time consuming, so it should not be used indiscriminately. Rather, the TCT should be applied only for one of several well-defined reasons.

The TCT is an excellent tool for diagnosing safety and operational problems of intersections that have previously been singled out for attention, usually because of an adverse accident history. It is not, however, appropriate for identifying hazardous intersections, because of the cost per intersection required for its application. However, traffic conflicts are well suited to confirming (or denying) suggestions that a specific site has an accident problem or has inherent safety problems not yet illuminated by an extensive accident history. Typical sources of such suggestions are citizen complaints, a prominent serious or fatal accident, or a short-term rash of accidents at a particular intersection.

The TCT is also applicable to before-and-after evaluations of intersection improvements, both on a site-specific basis and in gathering research data on countermeasure effectiveness. One must be careful, however, in order to ensure that changes in conflict counts are causally and logically related to the type of improvement implemented.

Conflict Categories

The traffic conflict categories to be observed and recorded in the field should be reliable, repeatable, practical, and have at least face validity, if not a strong accident correlation. Following these guidelines, the conflict categories that should be used are right turn, same direction; left turn, same direction; slow vehicle, same direction; opposing left turn; right turn from right; cross traffic from right; left turn from right; cross traffic from left; and left turn from left. For each of these, secondary conflicts should also be observed and recorded. Simultaneously with conflicts, main-line traffic volume should be counted. The observers should always note any special occurrences, particularly the apparent cause of slow-vehicle conflicts.

Preliminary observation of a site, accident records, or citizen complaints may indicate that other, more specialized categories might also be noted in certain instances. These special categories include right turn on red, lane change, pedestrian, and bicycle.

For an analysis of conflict counts, certain categories should be combined to obtain more robust figures. First, the secondary conflicts should all be summed with their respective causative conflicts. Then, the following sums should be created: all same-direction conflicts; opposing left-turn and left-turn, same-direction conflicts; all conflicts involving vehicles from the right; all conflicts involving vehicles from the left; and all conflicts involving cross traffic.

Conflict Observations

Traffic conflicts can be observed at an intersection by either one or two persons. In either case, individuals should observe opposite legs of the intersection alternately. A basic work segment of 30 min is recommended. In each segment, traffic conflicts should be observed for 20 min. The other 10 min should be used for recording the counts and other data and for moving to the opposing leg. Detailed conflict-observation procedures are described in the research report previously cited (3).

Application of Conflicts Results

The numbers of conflict counts to be expected, or even those numbers that are indicative of safety or operational problems, cannot be stated unequivocally at present. Sufficient research on this topic has not yet been accomplished. However, several things are apparent. First, the counts, themselves, are not useful comparative indicators. Even the limited number of intersections used in this study illustrated the extreme variations in counts between nominally similar intersections. Counts should be normalized (divided) by traffic volumes, yielding conflict rates. The main-line volumes appear to be most appropriate for this purpose, rather than total volumes, cross-traffic volumes, etc. Table 4 provides some guidance as to average conflict rates and standard errors for various types of intersections.

To evaluate intersection improvements, conflict counts may be used in before-after comparisons, provided no major changes in traffic volumes have occurred. The counts may be compared by using standard statistical tests such as t-tests, provided transformations are first applied, as discussed in Glauz and Migletz (3).

Training and Implementation

An agency that intends to use the TCT should be aware that properly trained and experienced observers are necessary for success. Otherwise, only inaccurate and unreliable data can be expected. Available options are to (a) contract such work with qualified consultants or (b) train and maintain traffic technicians in house. The latter option may be most cost effective if use of TCT will be widespread; the former may be more appropriate for occasional needs or unusual applications (e.g., nights or weekends).

Training concepts are presented in the report previously cited (3). There is no substitute for field practice and experience, which will accustom the trainees to the variety of real-world happenings and help them develop a consistency of interpretation.

CONCLUSIONS

1. The use of the TCT at intersections is most suitable for diagnosis, improvement evaluation, and confirming or denying the presence of safety hazards or operational problems at suspect locations. It is not recommended for routine hazardous-location identification because of the large amounts of data collection that would be required.
2. Traffic conflicts data should be viewed as supplements to, not replacements of, accident data.
3. The recommended traffic conflicts data can be obtained reliably by traffic technicians who have moderate training, a minimum of special abilities, and no equipment other than a mechanical count board and a watch.
4. Traffic conflicts, as stochastic traffic events, vary quite markedly in number and rate from day to day, even under nominally identical conditions, just as do other traffic events such as accidents and turning volumes. Thus, they are not as repeatable as would be desirable.
5. Cross-traffic and opposing left-turn accidents are usually the most prevalent and serious safety problems at intersections. The TCT is particularly useful for these problems.
6. Rear-end accidents at intersections seem to be more strongly associated with main-line traffic volumes than with rear-end conflicts, although observations of the latter may help to discover the reasons for rear-end accidents.
7. The identification of severe conflicts, as distinguished from others, may be of general interest, but they occur too infrequently to be of use as diagnostic or evaluative measures.
8. The amount of data collection needed to obtain reasonably precise conflict-rate estimates depends on the type of conflict and the type of intersection but is typically on the order of a few hours to a few days.

9. Traffic conflicts and traffic conflict rates (especially severe conflicts) increase substantially from about 2:30 p.m. through about 5:00 p.m.

10. The training of persons in the TCT should rely heavily on supervised and/or critically reviewed field practice.

RESEARCH NEEDS

This research led naturally to ways and means of implementing the observation, recording, and analysis of traffic conflicts. Methodologies, definitions, etc., that are operationally feasible have been determined, and no further research along these lines is recommended.

Two needs that relate to the application of the TCT at intersections are apparent. One need is to determine the relationships between traffic conflicts of certain types and accidents of analogous types. Suggestions regarding such relationships are now available, but much more work is required. The other important need is to establish norms and warrants for various categories of traffic conflicts, dependent on site characteristics. Expected, as well as abnormal, conflict-rate guidelines should be established for individual types of intersections.

The present research was limited to intersection conflicts. However, the literature contains many examples of other areas of application, including midblock locations, freeway entrances and exits, weaving areas, construction zones, and pedestrian crossings. Further research is needed to clarify and standardize procedures to be used for these other applications.

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Comparison of Three Loran Position-Determination Techniques in the Los Angeles Area

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A multiuser automatic vehicle monitoring system being developed for deployment in Los Angeles is discussed. In addition to the basic signpost technique to be used along transit routes and in the central business district, relatively inexpensive long-range navigation (loran) receivers will be used in a few vehicles to provide general location information over the entire 1000-km^2 (400-mile^2) Los Angeles Basin. Three techniques to convert loran time differences (TD) of arrival information to latitude and longitude were evaluated for accuracy, computation time, and memory requirements. The three methods are an empirical regression technique that uses best-fit equations to fit measured TDs to locations, a theoretical technique that uses a geometric earth model and a radio-wave-propagation model to determine location based on travel times from the known transmitters, and a combination technique that computes the position theoretically and then provides an empirical correction. All techniques gave approximately the same accuracy. It is possible that subdivision of the larger area into sectors could improve the overall accuracy to that of the central area, but not enough data were available to test this. It appears that TD grid warpages in the Los Angeles area are large enough and not sufficiently regular to be compensated for by standard techniques.

Automatic vehicle monitoring (AVM) systems provide the locations of members of a fleet of vehicles to a central control point. An AVM system will usually include radio communication links from the control center to the vehicles. The combination of location information and communications allows the efficiency of vehicle fleet use to be improved. For instance, police cars or taxis can be dispatched in an optimum manner, or transit bus drivers can be advised when they are exceeding permissible schedule deviations.

The Urban Mass Transportation Administration (UMTA) and the Transportation Systems Center are developing a multiuser AVM system to be deployed in a demonstration in Los Angeles (1). The basic fixed-route subsystem (for buses) uses low-power, high-frequency "signposts" at intervals along the routes covered. A portion of the central business district (CBD), including the high-rise area, will be furnished with signposts at a density high enough