PREDICTING INTERSECTION ACCIDENTS.

The Use of Conflicts and Other Models based on Traffic Flow Parameters to Predict Accident Experience at Non-Signalized Intersections.

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Ottawa

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Predicting Intersection Accidents
Errata Sheet

1. Page 24 - The upper diagram and two accompanying photographs belong under the previous heading of "Cross-Traffic Conflicts". Only the lower diagram and pictures define a left-turn conflict.

2. Page 81 - Table 12: Under each infraction heading the 2 X 2 matrix should read C, $\bar{C}$ and V, $\bar{V}$ from left to right and top to bottom respectively. Also the second equation in each case should read as follows:

$$P(C/\bar{V}) = \frac{C\bar{V}}{C\bar{V}+\bar{C}\bar{V}}$$

and the third equation:

$$P(C) = \frac{VC+C\bar{V}}{VC+C\bar{V}+V\bar{C}+\bar{C}\bar{V}}$$

FOREWORD

The intent of this report is to summarize the state of the art concerning the analysis and prediction of accidents at intersections and to describe a study recently conducted by the Road and Motor Vehicle Traffic Safety Branch of the Ministry of Transport to assess the efficiency of various accident predictor models, especially the concept of traffic conflicts.

The Universities of Toronto, New Brunswick and British Columbia, under contract to the Ministry of Transport, collected much of the data for the study, with subsequent analysis performed by the Road and Motor Vehicle Traffic Safety Branch.

This report represents only a preliminary analysis of the problems of accident prediction at intersections and, as such, the conclusions reached must of necessity be tentative in nature and relate more to directions for future research than to specific implementation policies. It is hoped, however, that the results of this study and the contents of this report will provide useful information to those agencies involved in traffic and accident analysis.

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ABSTRACT

This report describes a study undertaken by the Ministry of Transport in order to evaluate various models for the prediction of accident occurrence at intersections. Variables considered were: traffic volumes, vehicular manoeuver times, traffic conflicts and violations.

Significant correlations were found between accidents and conflicts, accidents and intersection approach volumes and accidents as a function of a time-volume exposure index.

While the data tended to support the hypothesis that accidents and conflicts are related, the correlations achieved were not of a high order and it was found that the concept of vehicular conflicts, in its present form, is not likely to result in a viable tool for the analysis of individual intersections. A possible exception to this general conclusion may be in the area of identifying hazard spots within an intersection.

It was found that the best accident predictor models were those based on vehicular volumes. The inclusion of a time exposure factor, while not improving the overall correlation, nevertheless gave indications of explaining some accident variance in situations where consideration of volume alone was insufficient.

1. INTRODUCTION

About half of all accidents occurring in urban areas take place at intersections, and in rural areas, about one quarter.

In terms of road mileage this is a disproportionate figure but it is readily understandable when the relative level of complexity of driver action is considered.

At no other point in the roadway or highway system, whether urban or rural, is the level of driver decision requirement so high or the penalty for mistaken judgment so great.

Because grade separation is simply economically and geographically impractical for urban intersections and also many rural ones, the at-grade "Tee", 4-leg or multi-leg intersection are familiar and permanent fixtures.

Signal control should intuitively provide some measure of protection against accidents but often it appears that stop-and-go type signalization actually increases accidents since it is primarily designed as a tool to increase capacity and reduce delay rather than to improve safety. The long-held assumption that signals improve traffic flow patterns and must thereby reduce accidents has recently been seriously questioned.

While a number of studies are recorded in the literature dealing with specific intersection characteristics or attempting to correlate accident occurrence with certain measures of flow, very little seems to have been attempted by way of a comprehensive analysis of motor vehicle behaviour at intersections combined with the characteristics of the junctions themselves.

The following study was initiated in an attempt to define and record vehicular behaviour at intersections and in doing so to investigate many of the empirical and theoretical approaches to accident prediction which have been propounded in the past or are currently in use.

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2. ACCIDENTS AT INTERSECTIONS - A REVIEW OF THE LITERATURE.

2.1 Prediction of Accident Occurrence at Intersections.

2.1.1 The Theoretical Approach

In developing a theory of accident occurrence at intersections there are two basic steps which must be considered independently.

The first is vehicular exposure. A vehicle, by its very presence on the road, is exposed to the possibility of being involved in an accident, but when it negotiates an intersection the notion of exposure becomes much more specific and more easily defined in concept. It is not difficult to see for instance that a car on a secondary road in the act of crossing a more major route where no protected movements are provided, is exposed to a right-angle collision for the length of time required to cross. This exposure is a function only of the vehicle in question and the nature of the road or intersection geometrics and does not involve other traffic.

Once a vehicle becomes exposed in the intersection area, however, a second step in the analysis must be taken. This involves the probability that, once exposed, the vehicle will be hit by another. Now the other traffic streams must be considered since the probability of collision is simply the probability of two or more vehicles occupying the same place at the same time.

But here the analysis becomes clouded. Exposure can be represented in a number of valid ways, among them traffic volumes and movement times, since all that is required is an expression for the presence of vehicles at a certain location in space. On the other hand, the probability of collision is a far more complicated concept which involves several unpredictable factors such as driver reaction and vehicular response. The best that can be done is to compute the statistical likelihood of two vehicles simultaneously occupying the same space assuming that speed and direction remain unchanged, that is, no evasive manoeuvers are taken. This is the approach chosen by Roer (33) although his concept of exposure includes the probability of collision.

Such a definition however would result in grossly overestimating the number of accidents since in most cases an actual collision is avoided by means of evasive action on the part of one or both drivers. What this approach does define however is the concept of vehicular conflict which is independent of the subsequent driver action or vehicular response. This fact has been recognized by Chapman (7) who has employed the exposure-probability product to predict conflicts at intersections which are then compared to observed situations. Unfortunately, like many similar theoretical studies, the analysis is not supported by much observational data.

In order to reconcile the discrepancy between accidents and conflicts it is necessary to compute a factor representing "collision rate" (33) or collisions per exposure. This has been done by McDonald (23) and Webb (46). A number of authors have approached the problem by assuming a "critical time period". Surti (42) has chosen three-quarters of a second for collision occurrence and a time of one-quarter second has been assumed by Breuning and Bone (5) in a similar analysis.

One aspect of intersection accident probability which is often not considered is that different classes of accidents may have varying probabilities of occurrence depending upon the nature of the intersection itself and the extent of vehicular movement permitted. Surti (42) enumerates the possible points of conflict at an intersection but assigns them all the same probability of accident occurrence. Even so his method does distinguish between different geometric and traffic movement situations which are not covered in a gross consideration of traffic volumes. As with the study by Chapman, however, the thesis is weakened by a lack of actual corroborative data.

2.1.2 The Observational Approach

2.1.2.1 Traffic Volume Relationships

While the theoretical method postulates a theory and then seeks to justify its selection by comparing prediction to actual occurrence, the observational technique compares and correlates quantities of data, usually obtained from actual observation or measurements, in an attempt to establish trends or empirical relationships.

In actual fact the distinction is not so clear-cut when dealing with intersection accidents since, as we have seen, even the so-called theoretical developments rely upon assumptions based largely on empirically derived expressions.

In terms of concept, hovever, the observational approach is completely opposite to the thecretical method. McDonald (23) investigated 171 at-grade intersections along 180 miles of an expressway route, obtaining 24 hour traffic volume counts for both main and secondary roadways. From this and prior accident histories he attempted to relate accident occurrence to ADT entering the intersection from both main and secondary routes. The results published indicated that the number of accidents varied with the product rather than the sum of approach volumes and was far more sensitive to changes in crossroad than main road volume.

Also using volume as a measure of vehicular exposure, Heany (18), by comparing accident and traffic volume data, arrived at an empirical expression relating yearly accidents to the sum of intersection approach volumes. Data from 252 intersections were employed and Heany reported a "high positive correlation". Based on the standard deviation of the data, Heany developed a decision model for identifying dangerous intersections which he tested prior to and following intersection improvements and achieved significant results.

Thus there seems to be considerable disagreement as to the nature of the accident-volume relationship and, to further complicate the picture, one study (unpublished data from the city of Hamilton, Ontario) did not indicate any significant correlation using either volume summation or product.

2.1.2.2 <u>The Concept of Conflicts</u>

While accidents themselves are the obvious measure of the safety of an intersection it has long been recognized that their relative scarcity, in the sense of experimental data, mitigates against obtaining statistically significant relationships without considering many years of collision history. This becomes unacceptable when attempting to evaluate the effects of improvements and countermeasures or when studying a relatively new intersection. What is required is a substitute for accidents which can be observed in sufficient quantity in a short period of time.

The concept of accidents as the apex of a triangular data base progressing from exposure or vulnerability to actual collision is commonly employed, and in this system the category underlying accidents is that of vehicle conflicts.

The idea of using conflicts to predict accidents was first promoted by the General Motors Corporation in a research paper by Perkins and Harris (32). The authors defined a series of conflict situations and developed a method for recording these conflicts at intersections.

One of the major problems in employing the conflict technique occurs in the definition of a conflict. Conflicts can range from precautionary to near-miss situations with categorization being at best somewhat subjective. Thus replication and comparison between separate studies can be very difficult.

Perkins and Harris employed a very broad definition of conflicts including all incidents from precautionary action to near-miss. In fact, they proposed the recording of all brake light applications as conflicts.

Using this conflict definition the authors drew comparisons with accident statistics concluded that "a high level of association exists" (32). A subsequent analysis of their published data by Heany, however, indicates that the correlation coefficients are of a relatively low order (0.48 overall).

In fact, a similar conclusion was reached in England by the Road Research Laboratory who initially performed conflict studies using a broad definition similar to that of Perkins and Harris. The British investigators discovered that significant correlations could only be obtained when precautionary conflicts were omitted and those of the near-miss variety alone recorded. Spicer (39) concluded that the results of his detailed investigation of a rural intersection in England "allows acceptance of the hypothesis that serious conflicts and accidents are related, but not of the hypothesis that accidents and all conflicts are related". The use of near-miss conflicts was rejected by the G.M. team as being "highly subjective and non-repeatable" (32).

Campbell and King (6) used the G.M. method to record conflicts and volume exposure at two rural intersections in Virginia. Their findings indicated "no significant association between conflicts per vehicle and accidents per vehicle at the 0.05 level" (6). Because the authors noted that many of the rear-end conflicts previously counted had been precautionary in nature, they compared the data again, omitting both rear-end conflicts and accidents. Although the correlation was again not significant at the 5% level, there was nevertheless a much higher degree of association than before. This tends to confirm the British experience.

2.1.2.3 Other Indicators

Work is currently under way at the British Road Research Laboratory by Faulkner (11) towards the identification of accidents by means of debris remaining at the scene. In

England, such debris (glass, etc.) apparently often remains at the accident site for some time, usually on medians or traffic islands, and they have had reasonable success in correlating weight of collected debris with the accident history at a particular location. The advantage to this method is that it could allow investigators to arrive at a figure close to the actual number of accidents occurring rather than rely on reported accidents which may only represent a fraction of the total.

2.2 Methods for Developing and Evaluating Countermeasures

2.2.1 Before and After Studies

Considerable use of so-called "before and after" studies has been made in order to evaluate the effectiveness of specific improvements, or what were thought at the time of installation to be improvements. Such studies have often showed that a device generally thought to have a beneficial effect on intersection safety in actual fact may have little or no effect and sometimes even an adverse effect.

Such a finding was reported by McMonagle (24) and Soloman (38) concerning a study of traffic signal effectiveness in Michigan. McMonagle conducted detailed before and after studies on five intersections, three of which had received stop and go signal systems, the remaining two having been given a flasher warning system. An analysis of the accident histories showed that accidents increased at the stop and go signal controlled intersections by 12%, 700% and 50% respectively. While injuries also increased somewhat, the main increase was in property damage accidents.

Six years later, based on a much larger data sample, Soloman compared accident statistics for 89 intersections before and after installation of traffic signals. He found that after stop and go signal installation rear-end, head-on and sideswipe accidents rose 200%, 157% and 75% respectively with only angle and miscellaneous collisions decreasing. The installation of flashers, however, was found to have resulted in a nearly uniform accident reduction of about 25% for all collision types.

The study did not take into account or investigate flow improvements.

Newby (28) evaluated twelve four-way junctions in England and concluded that the installation of traffic signals with an all red period had significantly reduced cross-road accidents in a two-year "after" period.

A similar "before and after" method was adopted by Schoene and Michael (35) in evaluating the effects on accident occurrence of signal installation at a number of intersections in Indiana. They found that while right-angle accidents normally decreased, the rear-end variety increased and remaining accident types more often increased than decreased. Fatal and injury accidents were also found to have increased by 26%.

Before and after studies conducted by the Ohio Department of Highways (30) concerning flashers, showed that overall accident rates were reduced but that apparently the conspicuity of the devices (various designs were evaluated) seemed to have little effect on accident record. They achieved most success in accident reductions with a "bouncing ball" type flashing device.

The effects of several types of minor improvement were evaluated by Hammer (15). He found that left-turn channelization was effective in reducing accidents from 32% (paint) to 64% (protected) and that four-way stop signs produced reductions in right-angle accidents at unsignalized intersections.

This last finding is confirmed by Heany (17) who recorded an 87% reduction in total accidents at 57 intersections during one year following four-way stop sign installation. At these intersections, fatalities were also eliminated and injuries reduced by 91%.

2.2.2 Identifying High Risk Components

When sufficient "before" data is lacking or when it is uncertain which intersection factors should be evaluated in detail, studies have often been initiated to investigate a range of functions or traffic controlling factors at intersections to determine the relative effect of each on the overall safety at the junction.

Two papers from the British Road Research Laboratory summarize the effect on accidents of various geometric design components and related driver behaviour.

Charlesworth and Tanner (8) summarized the results of investigations into accidents and driver behaviour at rural junctions and based on these, presented some recommended design principles. Tanner's analysis of accidents at three-way rural junctions resulted in the deduction that accidents between major road vehicles and turning, minor road vehicles was approximately proportional to the square root of the product of the flows. This is similar to the findings of

McDonald (23). Not unexpectedly they found that by far the highest risk manoeuver was that of turning across opposing traffic lanes on dual highways.

The authors also concluded that staggered crossroads are safer than the normal straight-over variety and that the provision of roundabouts at intersections can result in a significant reduction of injury accidents.

A similar type of paper has been prepared by Colgate and Tanner (9) dealing with the effect of layout and traffic flow on the frequency of injury accidents at 139 rural three-way junctions in Britain. Their results confirm those of the earlier study above, but the investigation of further factors such as visibility did not prove conclusive.

Preliminary results from a Minnesota Highway Department investigation into right-turn-on-red vehicle movements (26) indicate that accidents occur during this procedure largely in instances of increased exposure or high main road traffic. This relationship of accidents to exposure can once again be used as a justification for the enumeration of vehicular conflicts at intersections to identify dangerous areas or manoeuvers.

Such studies are currently being conducted at the Road Research Laboratory (39) in an attempt to locate high-risk sections of certain rural junctions and to suggest the most efficient countermeasures.

3. INTERSECTION TRAFFIC AND ACCIDENT STUDY

3.1 Background

3.1.1 Pilot Investigation - 1971

The Road and Motor Vehicle Traffic Safety Branch of the Ministry of Transport first became involved with traffic flow at intersections and specifically with the traffic conflicts technique in the spring of 1971.

At that time, based on the published work of Perkins and Harris (32) and talks with researchers at the British Road Research Laboratory, it was decided to institute a small pilot project utilizing students during the summer of 1971.

The principle objective of this project was primarily to investigate the definitions and observational techniques involved, since it was realized that only a major project of considerably greater scope could result in a proper evaluation of the significance of conflicts and other traffic parameters as accident predictors.

Accordingly a few intersections in the Ottawa area were investigated in detail, first using techniques similar to those recommended in the General Motors study (32) and then continually modifying procedures and definitions where it was considered advisable (see section 3.2, "Definition of Terms").

TABLE 1

TABLE OF SPEARMAN RANK CORRELATION COEFFICIENTS FOR COMPARISON OF THE PERCENTAGES OF ACCIDENTS AND CONFLICTS BY TYPE AT THREE OTTAWA LOCATIONS SURVEYED IN THE PILOT STUDY.

NOTES:- Coefficients corrected for ties where they occur.

- Conflicts and accidents are listed according to type: weave, rear end, right turn, left turn, cross-traffic.

Location	Conflict Definition	Accidents (%)	Rank	Conflicts (%)	Rank	Spearman Coefficient
Elgin and Albert	G.M.	18 21 2 15 44	3 4 1 2 5	6 73 3 16 2	3 5 2 4 1	-0.10
	RRL (2-4)	18 21 2 15 44	3 4 1 2 5	0 12 0 58 30	1.5 3 1.5 5 4	0.33
Elgin and Slater	G.M.	21 26 0 2 51	3 4 1 2 5	21 54 11 6 8	4 5 3 1 2	0.20
	RRL (2-4)	21 26 0 2 51	3 4 1 2 5	29 20 0 17 34	4 3 1 2 5	0.90
Chapel and Laurier	G.M.	6 21 3 0 71	3 4 2 1 5	3 44 11 7 35	1 5 3 2 4	0.60
	RRL (2-4)	6 21 3 0 71	3 4 2 1 5	8 0 25 0 67	3 1.5 4 1.5 5	0.50

FIGURE 1 (A)

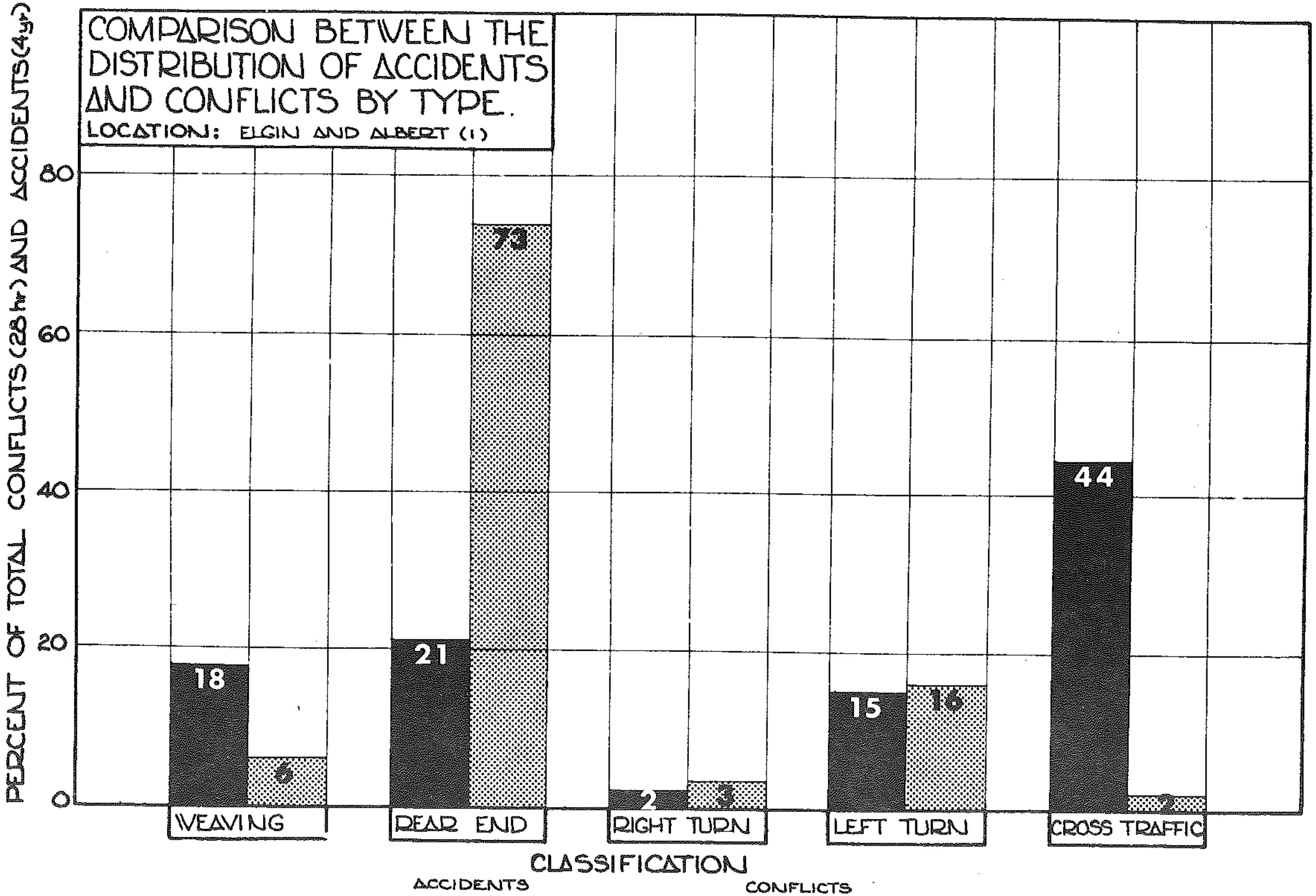

COMPARISON BETWEEN THE DISTRIBUTION OF ACCIDENTS AND CONFLICTS BY TYPE.
LOCATION: ELGIN AND ALBERT (1)
PERCENT OF TOTAL CONFLICTS (28 hr) AND ACCIDENTS (4 yr)
0
20
40
60
80
18
6
21
73
2
3
15
16
44
2
WEAVING
REAR END
RIGHT TURN
LEFT TURN
CROSS TRAFFIC
CLASSIFICATION
ACCIDENTS
CONFLICTS

FIGURE 1 (B)

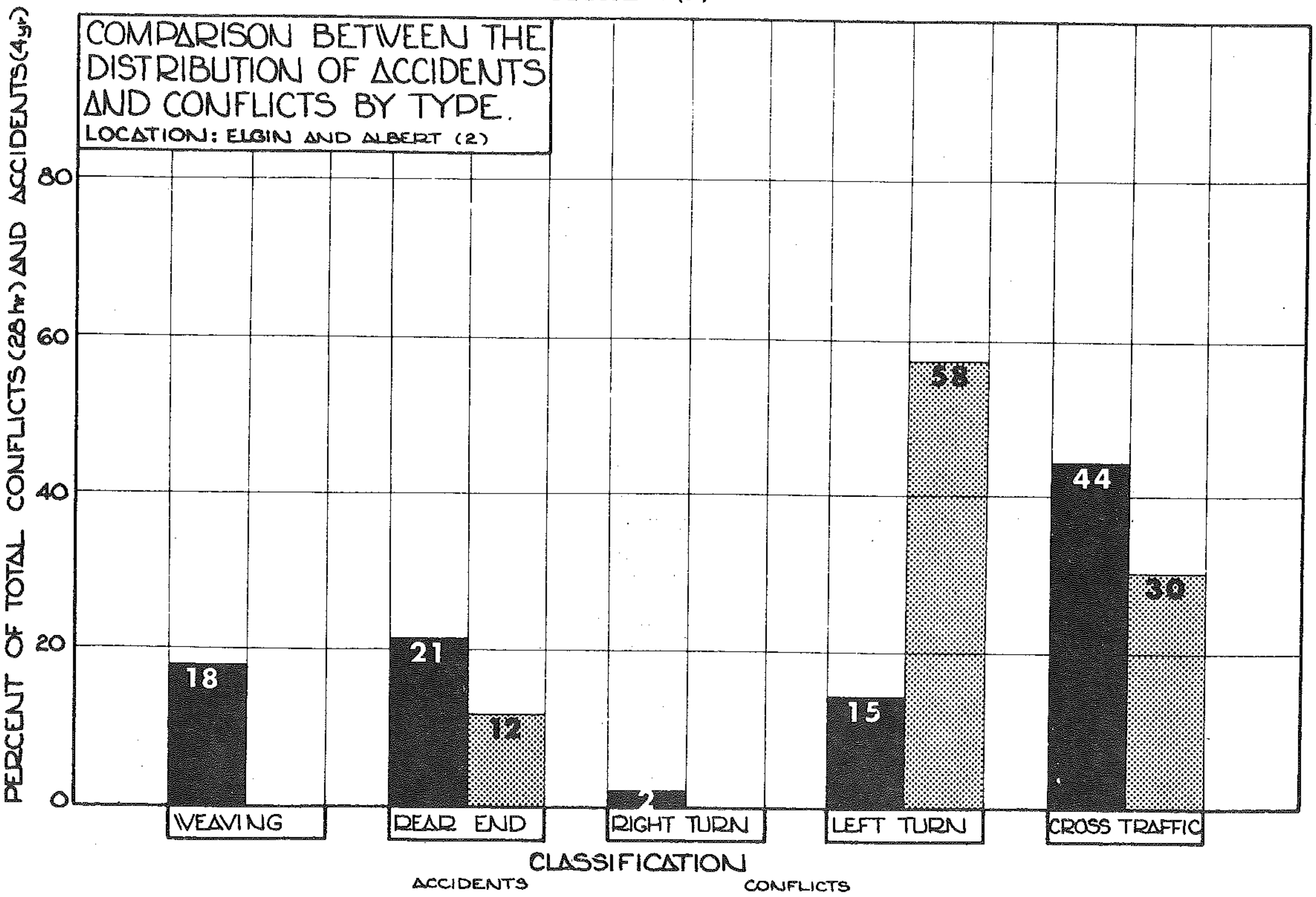

COMPARISON BETWEEN THE DISTRIBUTION OF ACCIDENTS AND CONFLICTS BY TYPE.
LOCATION: ELGIN AND ALBERT (2)
PERCENT OF TOTAL CONFLICTS (28 hr) AND ACCIDENTS (4 yr)
80
60
40
20
0
18
21
12
2
15
58
44
30
WEAVING
REAR END
RIGHT TURN
LEFT TURN
CROSS TRAFFIC
CLASSIFICATION
ACCIDENTS
CONFLICTS

FIGURE 2(A)

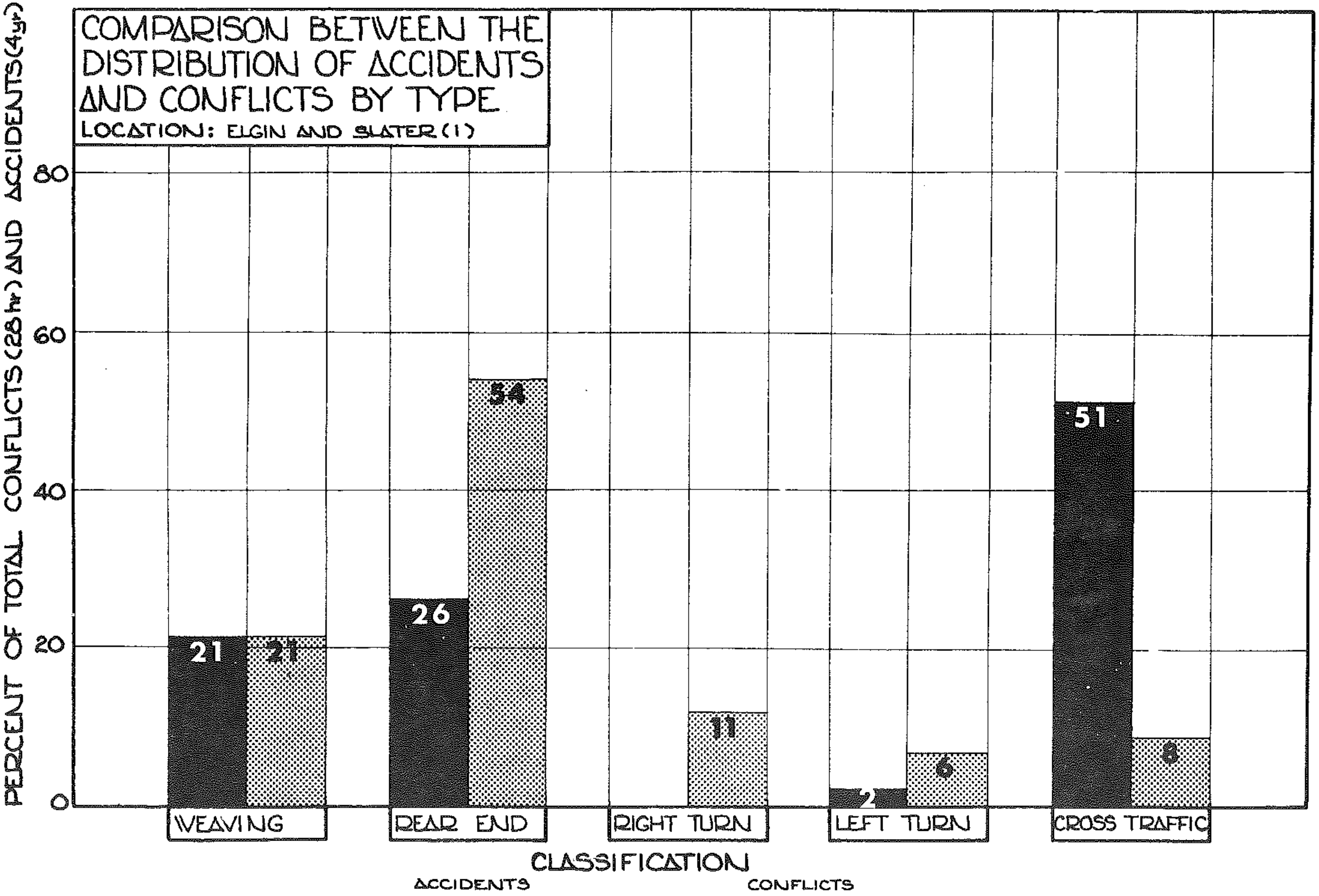

COMPARISON BETWEEN THE DISTRIBUTION OF ACCIDENTS AND CONFLICTS BY TYPE
LOCATION: ELGIN AND SLATER (1)
PERCENT OF TOTAL CONFLICTS (28 hr) AND ACCIDENTS (4 yr)
80
60
40
20
0
21
21
26
54
11
2
6
51
8
WEAVING
REAR END
RIGHT TURN
LEFT TURN
CROSS TRAFFIC
CLASSIFICATION
ACCIDENTS
CONFLICTS

FIGURE 2 (B)

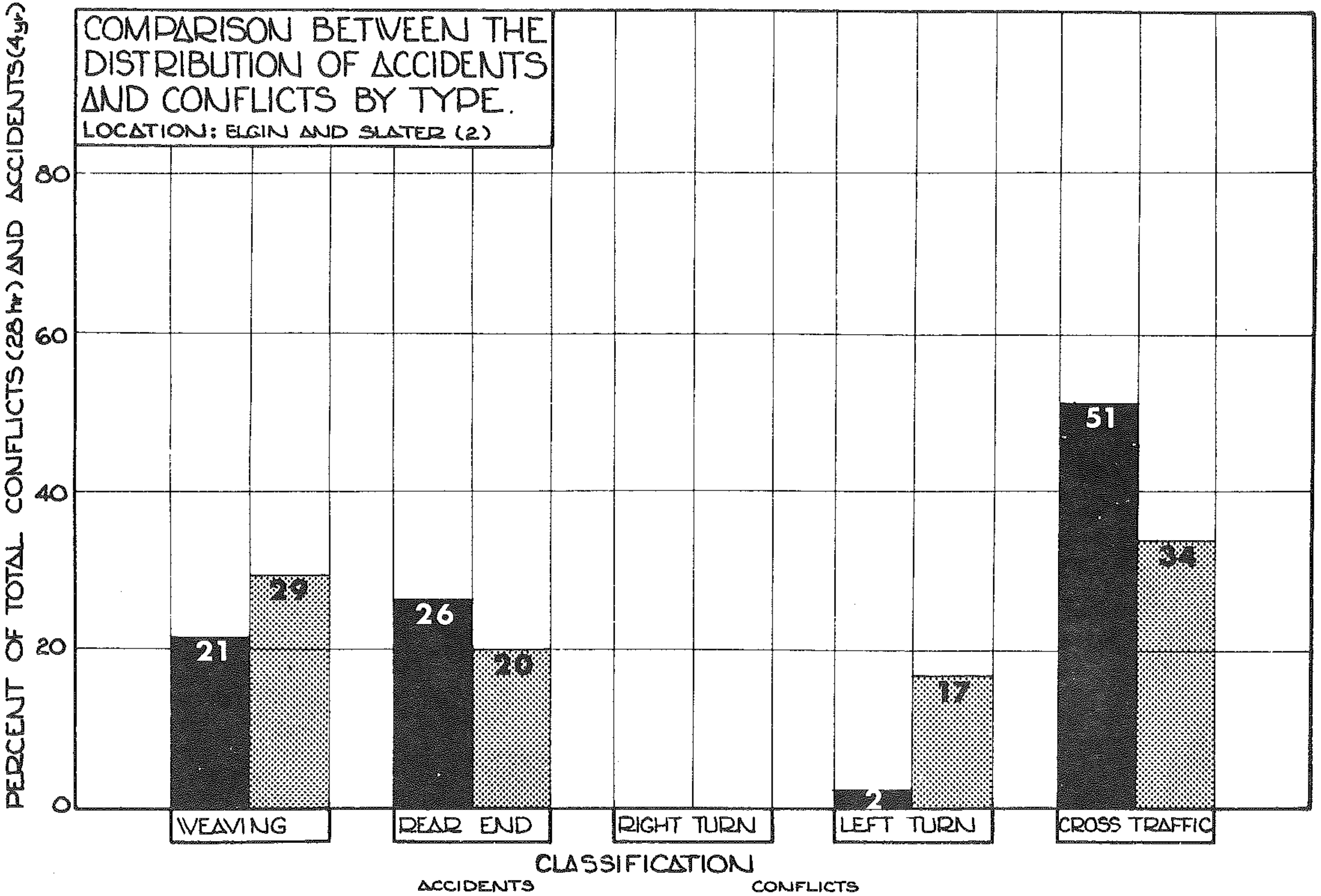
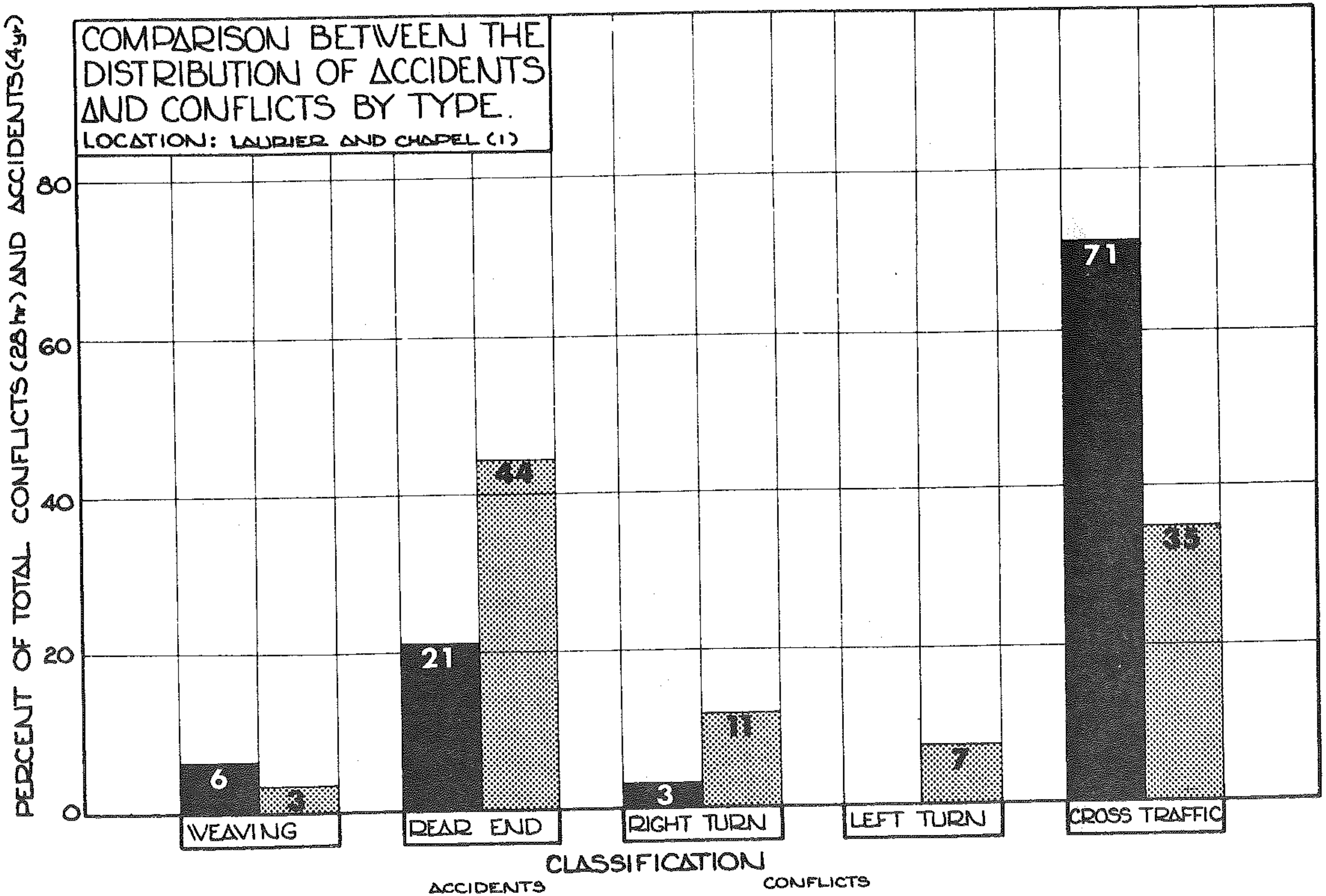
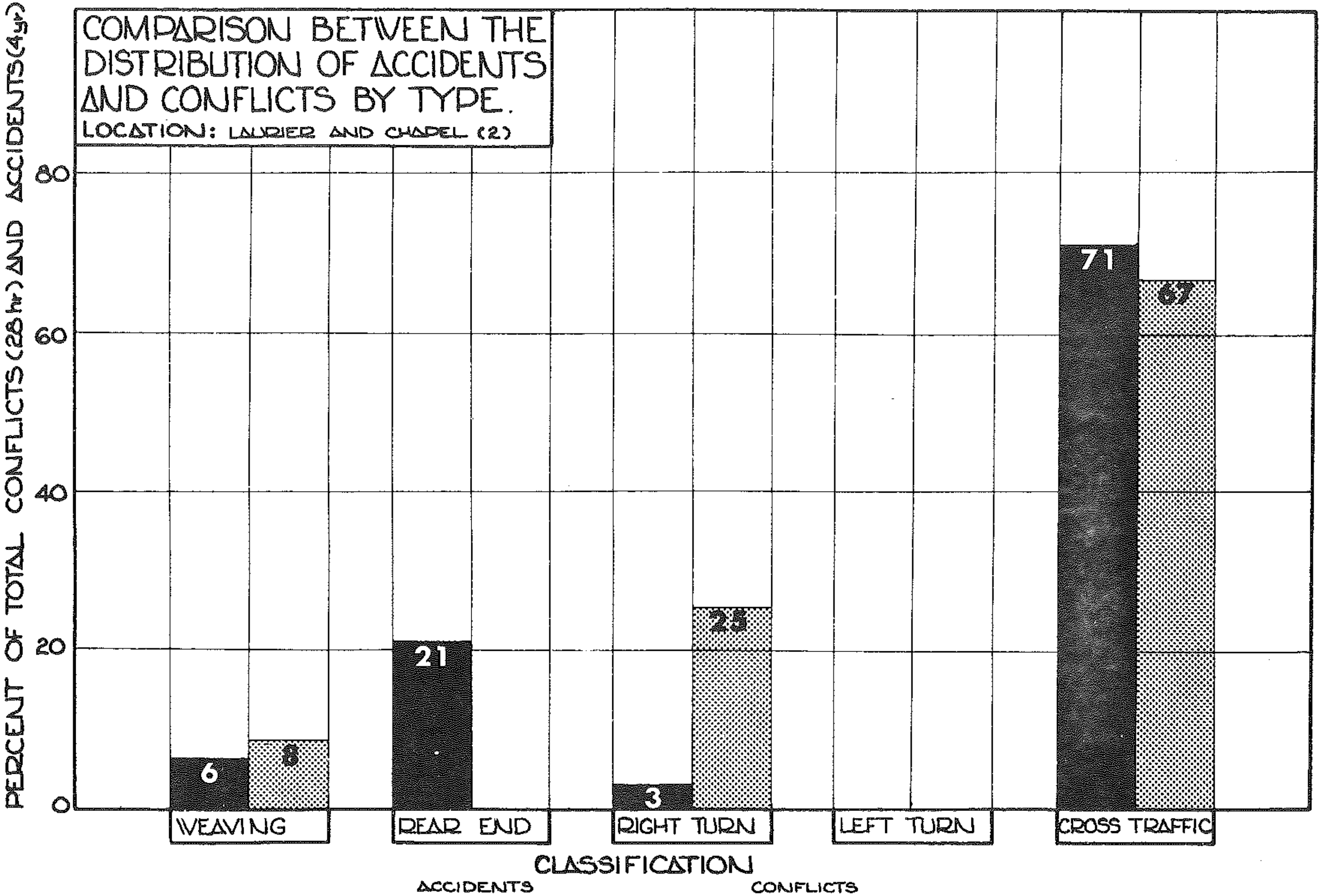

COMPARISON BETWEEN THE DISTRIBUTION OF ACCIDENTS AND CONFLICTS BY TYPE.
LOCATION: ELGIN AND SLATER (2)
PERCENT OF TOTAL CONFLICTS (28 hr) AND ACCIDENTS (4 yr)
0
20
40
60
80
21
29
26
20
2
17
51
34
WEAVING
REAR END
RIGHT TURN
LEFT TURN
CROSS TRAFFIC
CLASSIFICATION
ACCIDENTS
CONFLICTS

FIGURE 3(A)



COMPARISON BETWEEN THE DISTRIBUTION OF ACCIDENTS AND CONFLICTS BY TYPE.
LOCATION: LAURIER AND CHAPEL (1)
PERCENT OF TOTAL CONFLICTS (28 hr) AND ACCIDENTS (4 yr)
0
20
40
60
80
6
3
21
44
3
11
7
71
35
WEAVING
REAR END
RIGHT TURN
LEFT TURN
CROSS TRAFFIC
CLASSIFICATION
ACCIDENTS
CONFLICTS

FIGURE 3(B)


COMPARISON BETWEEN THE DISTRIBUTION OF ACCIDENTS AND CONFLICTS BY TYPE.
LOCATION: LAURIER AND CHAPEL (2)
PERCENT OF TOTAL CONFLICTS (28 hr) AND ACCIDENTS (4 yr)
0
20
40
60
80
6
8
21
3
25
71
67
WEAVING
REAR END
RIGHT TURN
LEFT TURN
CROSS TRAFFIC
CLASSIFICATION
ACCIDENTS
CONFLICTS

The Pilot Study had two major results, the first being the production of an Intersection Studies Manual to be used for training future teams of observers and the second being the selection of a conceptual definition of the term "conflict".

As has been reviewed in the literature section of this report, there have been basically two concepts of conflicts propounded. The General Motors researchers employed a broad definition which included precautionary driver actions while other investigators have suggested a more restrictive form which excludes these precautionary incidents. Table 1, in conjunction with Figures 1-3, illustrates the difference found in employing the two definitions and the basis upon which the decision was reached (in conjunction with the literature) to avoid the inclusion of precautionary actions in the counting of conflicts (see section 3.3, "Study Design").

3.1.1 Development of the Study

With the results of the Pilot Study indicating a justification for continuation, the entire project was expanded to include a broad and detailed analysis of traffic behaviour at intersections in relation to the past accident experience.

In order to broaden the scope of the investigation and account for regional differences in traffic patterns and driver behaviour, it was determined to undertake a study simultaneously in four major Canadian cities whose geographic location would provide reasonable coverage of the country as a whole.

It was also decided at this time that, since Canadian weather conditions tend to limit traffic studies to the summer months, the project could best be performed by university students and directly supervised by the Universities involved.

The above considerations led to the selection of the University of Toronto, the University of New Brunswick and the University of British Columbia for the formation of project teams. The fourth team was formed in Ottawa under the direct supervision of the Road Safety Branch of the Ministry.

The data collected by these four project teams during the summer of 1972 had led to the analysis and conclusions contained in this report.

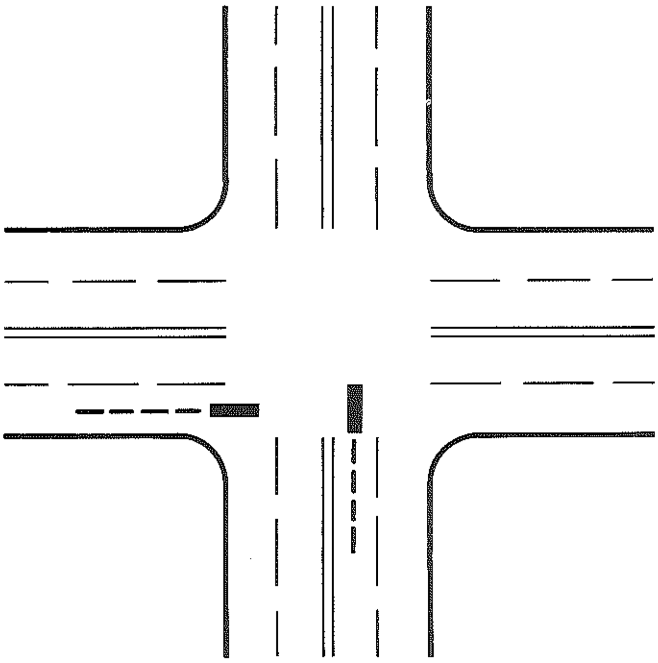
3.2 Definition of Terms

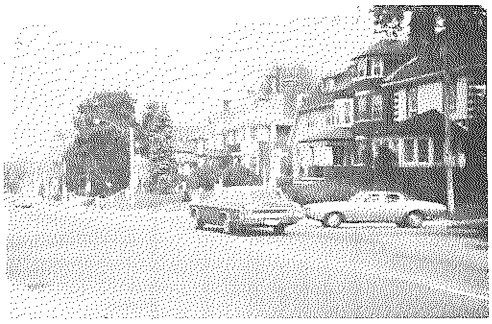
3.2.1 Conflict

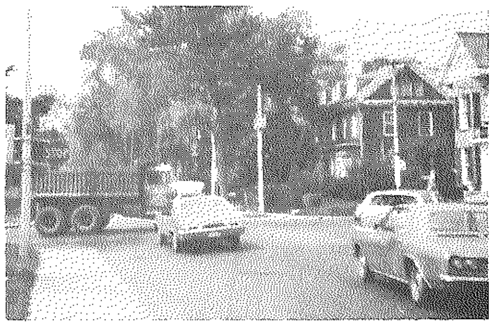
A conflict is considered to have occurred when the actions of one vehicle cause a second vehicle to take evasive action or brake to avoid collision.

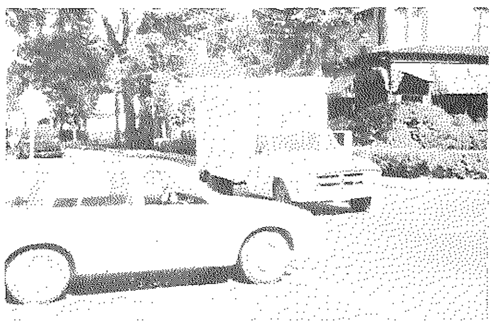
This definition was not extended to include precautionary or anticipatory actions on the part of the second vehicle or vehicles.

Cross Traffic Conflict - occurs when a vehicle conflicts with traffic on one of the approach legs crossing the direction from which it entered the intersection. This type of conflict may involve either a through or left-turn vehicle.

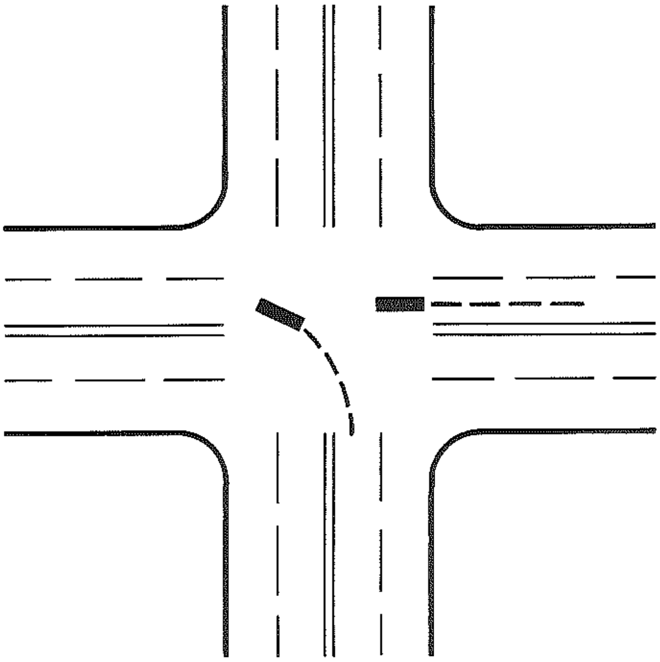


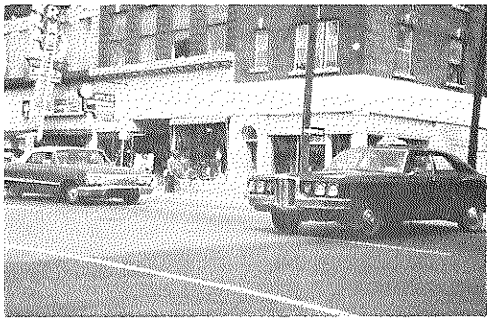


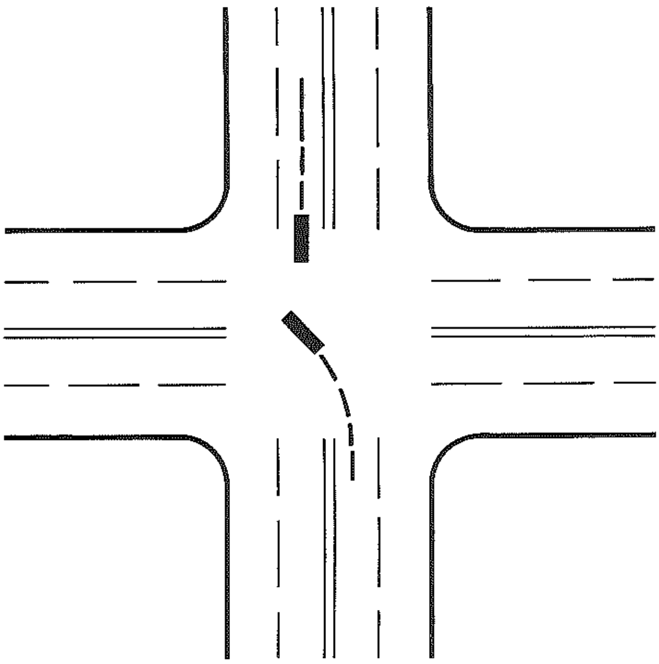


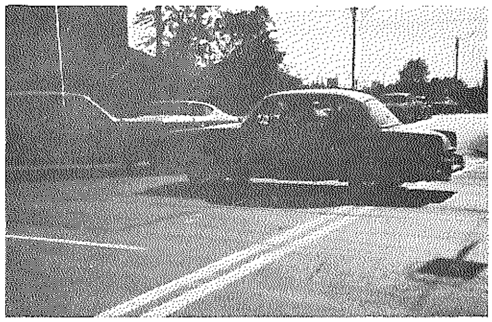


__Left Turn Conflict__ - occurs only when a vehicle making a left turn conflicts with through vehicles travelling in the opposite direction.

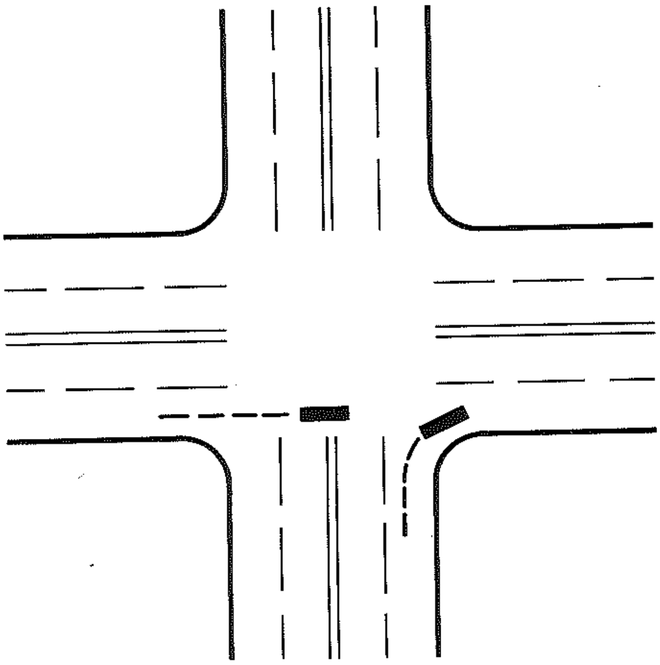


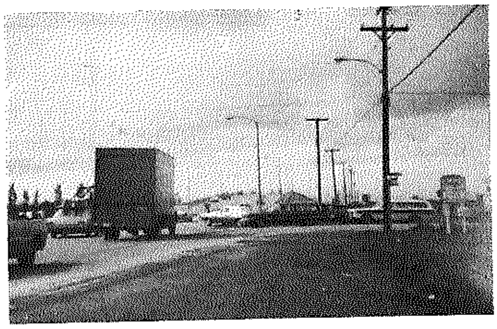




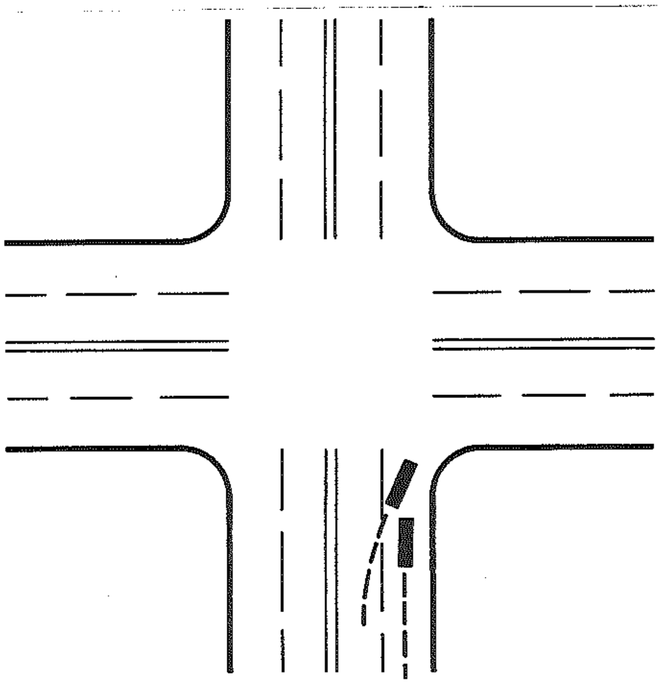


Right Turn Conflict - occurs when a vehicle making a right turn conflicts with through vehicles crossing the approach leg from which the vehicle is turning.





__Weaving__ __Conflict__ - occurs when a vehicle leaves its chosen lane, whether for purposes of passing or turning, and conflicts with an adjacent vehicle travelling in the same direction.

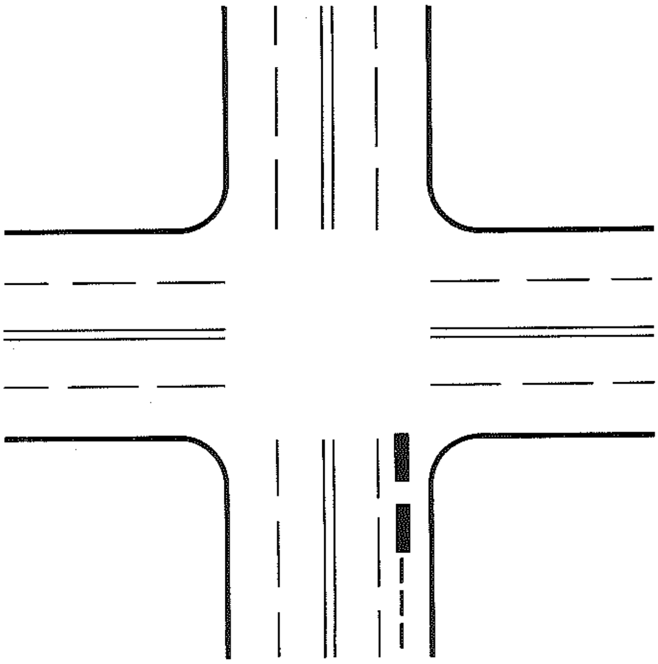


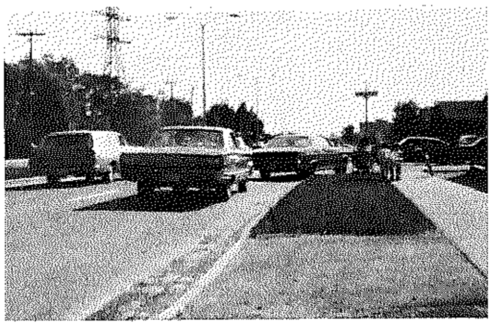
<u>Rear End Conflict</u> - occurs when a following vehicle is forced to brake or change lanes to avoid

(a) a vehicle slowing to make a <u>turn</u>,

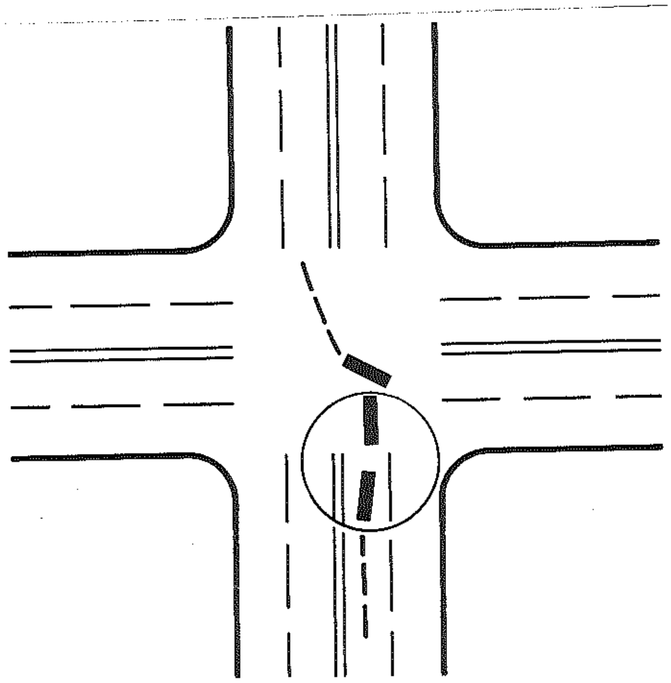
(b) a through vehicle stopping for a <u>control device</u>, or backed-up traffic,

(c) a vehicle slowing or stopping to avoid a <u>previous conflict</u>.



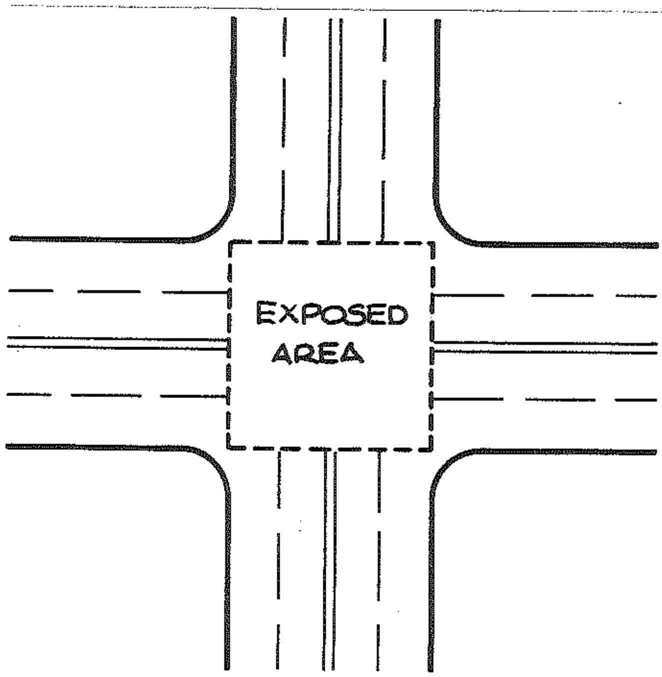


<u>Secondary Conflict</u> - any conflict which occurs as the result of a previous conflict.



3.2.2 Exposure Time

The exposure time for a particular manoeuver is the average time taken for vehicles to complete the manoeuver where for purposes of standardization the exposed area of the intersection is defined by the rectangle formed by joining the tangent points of the main leg curvatures at the corners of the intersection. Time is only counted for periods when a vehicle is actually exposed to other conflicting traffic.



3.2.3 Violation

A violation is regarded as any vehicular action which contravenes the dictates of the Highway Code or Municipal traffic bylaws in the study area.

3.3 Study Design

Based on the review of the literature described previously a number of factors emerged as possible accident indicators:

i) conflicts (Ref. 32, 6, 39)

ii) volumes (Ref. 33, 7, 23, 18)

iii) exposure times (Ref. 42, 5)

iv) violations (Ref. 32 - specifically red light violations)

Indications had also been obtained (Ref. 6 and unpublished U.K. data) that at least two classifications of conflicts are desirable in order to separate out those of only a precautionary nature which may not relate well to accidents.

This division of the conflict definition was rejected by General Motors researchers but, since other investigators have found it helpful, it was determined to attempt to follow some such procedure.

Following are aspects of the study design associated with the specific factors to be investigated.

3.3.1 Conflicts

The Road Research Laboratory in the United Kingdom has employed a progressive scale of 5 definitions in describing and recording motor vehicle conflicts at intersections.

These are:

1)	Precautionary conflict. (i.e. braking for vehicle waiting to emerge, precautionary lane change, or anticipatory braking.)	PRECAUTIONARY CONFLICT
2)	Controlled braking or lane change to avoid collision but with ample time for the manoeuver.	CONFLICT
3)	Rapid deceleration, lane change or stopping to avoid collision, resulting in a near miss situation. No time for steady controlled manoeuver.	
4)	Emergency braking or violent swerve to avoid collision resulting in very near miss situation, or occurrence of a minor collision.	
5)	Emergency action, followed by collision.	ACCIDENT

To simplify the recording process, since much other data was to be collected at the same time, and since it was not deemed practicable to attempt to make a formal distinction between 2, 3 and 4 due to the inherent variability of observational procedures, a conflict was defined for the purpose of this study as comprising categories 2-4 alone. Item 5, accidents, and item 1, precautionary conflicts, were omitted.

The omission of precautionary conflicts was a direct result of the information contained in the literature (6, 39) supplemented by the experience gained in the preliminary pilot study conducted by the Ministry in the summer of 1971 during which both definitions were briefly investigated with results similar to those reported by Campbell and King (6).

The selection of the length of conflict counting at each intersection was based on the General Motors recommended procedure and U.K. practice. A study period of two, 14-hour days (counted in four-7 hour days) was selected as a reasonable compromise for the recording of conflict data since it would allow for the completion of the greatest number of intersections while still providing a check on the single day count. A 14-hour day (7:00 a.m. - 9:00 p.m.) was decided upon in order to ensure that all traffic conditions were fully covered. The number of observers employed in a study team was 4, with a field supervisor to coordinate their efforts and check their placement and counting accuracy.

The study was conducted on weekdays only. While Mondays and Fridays are normally considered atypical traffic days, they could not be omitted due to scheduling problems and thus were included. Since the accident records did not indicate, however, any significant difference between these days and the remainder of the week, this was not considered to be an important factor.

3.3.2 Vehicular Volumes

Volume counting procedures were made similar to those for conflict counting except that it was felt that the greater amount of data involved would make a one-day (14-hour) count sufficient.

Since vehicular exposure times were to be investigated it was necessary to obtain the volumes involved in all through and turning movements.

3.3.3 Exposure Times

Since any theoretical approach to accident prediction requires a "critical time period" (42, 5) and since the related factor of vehicular speed has been mentioned (32) as affecting accident occurrence and severity at intersections, it was decided to measure both through vehicle speeds and average times required for all manoeuvres.

Since exposure times were expected to vary with traffic conditions the recording of data at each intersection was tkaen at three separate times: morning peak, off-peak and afternoon peak.

For purposes of recording times, a standard definition of the intersection area was selected to ensure that all times were recorded in the same manner and would reflect differences in intersection size and geometrics as well as specific sight restrictions and other factors (Section 3.2).

3.3.4 Violations

This factor was considered the least likely of the four to provide useful results with regard to accident correlation, but since it has been investigated by others (32) and represents an extremely high volume data source, this study was designed to include it. It was also felt that data on violations and resulting conflicts could help in developing an understanding of the effects of traffic laws on driver behaviour.

As with the recording of traffic volumes, one 14-hour day was considered sufficient for the counting of violations except in locations of low volume and complexity where the resulting lower violation rate might require a longer (two-day) recording period to amass sufficient data.

Unlike conflicts, violations can be defined specifically, and those identified ranged in severity from failure to signal turns to running red lights or stop signs.

3.4 Methodology

3.4.1 Selection of Intersections

Intersections were initially selected, with the aid of the City Traffic Department involved, to obtain a good range of accident experience over roughly similar volume ranges. The final selection was made following visual inspection in order to eliminate obviously atypical geometric configurations or complexity.

Reasonably complete accident histories were obtained for each intersection which gave sufficient details for each accident during at least the three years prior to the study to establish cause, type of accident, time of day and day and month of the year.

Finally, it was decided to restrict the study of non-signalized intersections so as to obtain a better sample of manoeuver conflicts and also it was hoped that, with the non-signalized locations, more problems would have remained uncorrected and thus present for analysis.

A total of 59 non-signalized intersections (51 urban and 8 rural) in four cities were selected for detailed study.

3.4.2 Composition of Field Study Teams

Each team generally consisted of four observers who stationed themselves at the various intersections so as to observe and record all conflicts and violations occurring on each approach leg, and a supervisor to check and coordinate their efforts and to approve the final tabulation of data. In some instances, where low-volume intersections were being studied, the number of observers was reduced.

3.4.3 Training of Teams

Based on the G.M. technique and experience gained in preliminary work, a Traffic Studies Manual was prepared and forwarded to each of the teams for study. All conflicts, violations and exposure terms were defined and the procedures for taking and recording data set out. In addition, copies of specially prepared standard recording and summary sheets were provided.

After each team had studied the Manual and spent a few days in general traffic observation and intersection selection, a representative of the Ministry was sent to provide additional instruction and advice both in classroom and field situations, in order to ensure that procedures would be uniform among the different teams. One to two days were spent with each team.

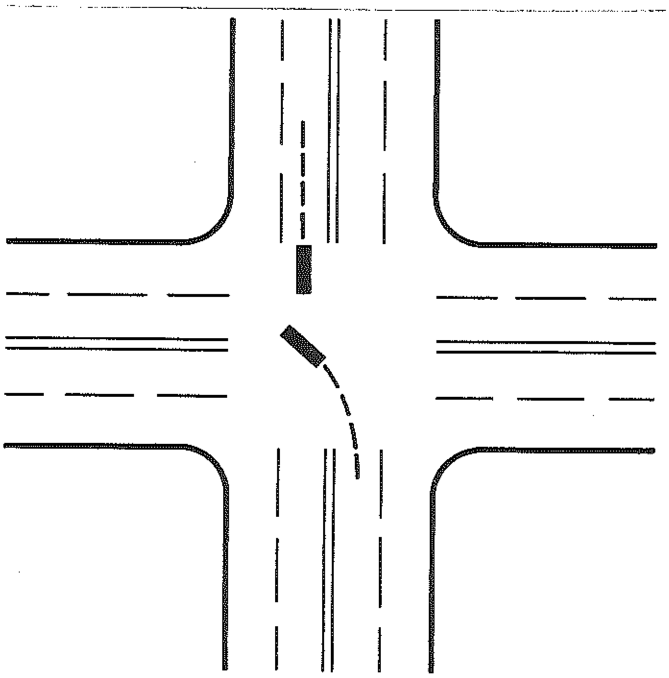
3.4.4 Conflict Recording Procedures

For recording traffic conflicts, the observers were not placed in any specifically defined location but rather it was left to the supervisor or team member in charge to ensure that each man was assigned an approach leg or intersection area and that he stationed himself in such a manner that he could see and record all incidents occurring in his area of responsibility.

In traffic terminology generally, all traffic is referred to by the direction in which it is proceeding. The observers were therefore referred to in a similar manner, that is, the observer assigned to watch westbound traffic lanes was the westbound observer (W) etc. The sketches below illustrate some examples of observer responsibilities.

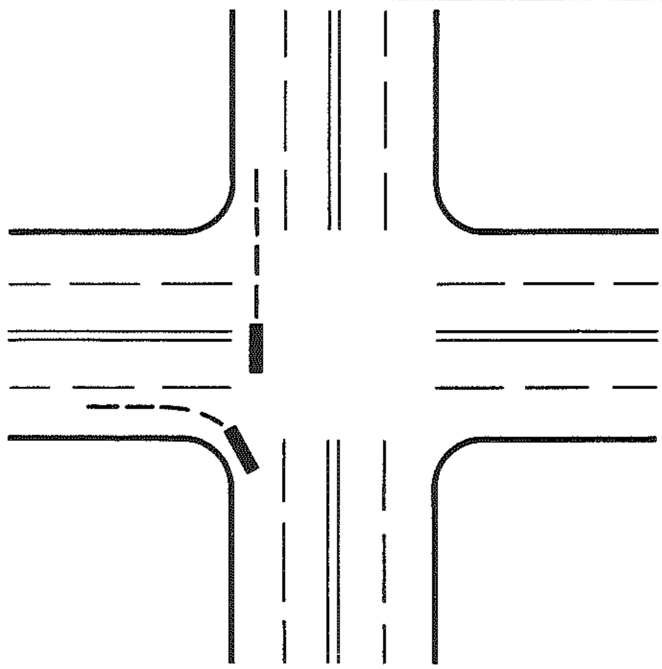
Example 1: Southbound car brakes to avoid northbound car which is making a left turn.

Observer Action: N counts one "left turn" conflict.



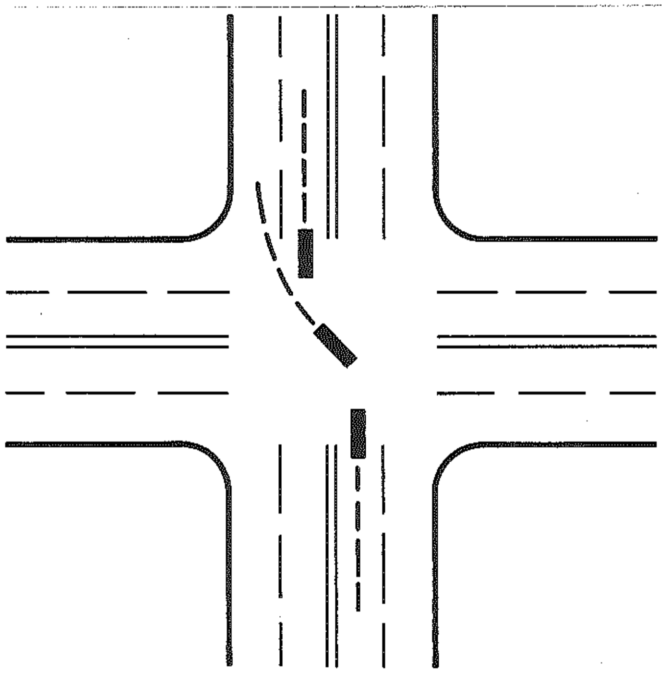
Example 2: Southbound car brakes to avoid rear end contact with eastbound car which has made a right turn after failing to stop at a stop sign.

Observer Action: E counts one "right turn" conflict and one "red light or stop sign" violation.



Example 3: Southbound car makes left turn from right hand lane and interferes with a second southbound car in the left hand lane as well as with rorthbound traffic.

Observer Action: S counts one "weaving" conflict, one "left turn" conflict and one "left turn from wrong lane" violation.



The general rule applied to recording conflicts was that a conflict was recorded against the offending or causing vehicle, that is, the direction in which this vehicle was proceeding prior to making the manoeuver.

Each observer transferred the totals to a summary sheet once every hour.

3.4.5 Volume Recording

At each intersection a preliminary study was made prior to any conflict or volume counting. During this period a detailed, scale drawing was prepared of the intersection and the various movement or channelization characteristics were noted.

From this information the allowable vehicular manoeuvers were enumerated and immediately following the conflict count the traffic volumes executing these various movements were counted and recorded for one 14-hour period.

Figures were transferred to summary sheets at hourly intervals.

3.4.6 Recording of Violations

This was accomplished in an identical manner with that employed for conflicts although it often proved a much more formidable task owing to the large number of violations encountered.

Because of this, the counting period was in most cases restricted to one 14-hour day.

All violations were recorded and categorized regardless of whether or not they resulted in potentially dangerous situations, but where a violation was the direct cause of a conflict, this was noted on the conflict summary sheet.

The violations were recorded on the same summary sheets as conflicts, and at the same time intervals.

3.4.7 Timing of Vehicular Movements

Recording of vehicle exposure times was carried out either during the preliminary study at each intersection or during the period of volume counting.

Three sets of readings were obtained for each intersection coinciding with the two peak volume periods and one representative off-peak period.

For each possible manoeuver at each daily period, a minimum total of 12 timings were taken for traffic of normal composition, that is, exceptional vehicles such as buses or tractor-trailers were not timed unless they represented a significant proportion of the local traffic. Of these 12 readings, the highest and lowest were rejected and the remaining 10 averaged to obtain the exposure time.

These exposure times were recorded along with average speeds of through vehicles (timed over a measured distance) on the same sheet as the scale drawing of the intersection. Thus they could easily be related visually to geometric characteristics and prevailing sight restriction.

3.5 Analysis of the Data

A review of the geometric characteristics of the various intersections revealed that the total sample of unsignalized locations should, for purposes of analysis, be divided in three groups: four-leg intersections of two-way streets, four-leg intersections having one, one-way street and three-leg or "tee" intersections. In addition to these groups, the data was also combined for all four-leg intersections and finally for the total sample of all intersections. Of the 59 intersections 13 were "tee", 37 four-leg, two-way and 9 four-leg, one-way.

3.5.1 Accidents and Conflicts

For each intersection the accidents and conflicts were divided into the five basic categories defined in section 3.2.1, that is, cross-traffic, left turn, right turn, weave and rear end. The first four categories combined are normally referred to as manoeuver accidents or conflicts since they generally involve a planned movement on the part of one or both vehicles.

The first consideration was to compare all conflicts with all accidents for the different types of junctions. Since some previous investigations (see section 2.1.2.2) had obtained improved results through omitting rear end conflicts, the next step was to compare all manoeuver accidents with manoeuver conflicts.

Following this, each category of conflict was compared with the corresponding accident type including pedestrian conflicts and accidents for which there was a small sample.

The statistic employed for purposes of comparison was the coefficient of linear correlation.

3.5.2 Accidents and Time-Volume Exposure Index

As a combined measure of overall exposure and manoeuver hazard at an intersection, the time-volume exposure index was developed (Appendix). This was based on relationships discovered by previous investigators (see section 2.2.2) and a simple dimensional analysis. While the index represented a combined theoretical and intuitive model it was hoped that the exposure times would provide additional information with regard to the dissimilar level of hazard to be expected from different vehicular manoeuvers at an intersection and that this, together with the volume-oriented exposure term would result in an improved accident predictor.

As with conflicts and accidents, linear correlation coefficients were calculated between all accidents and time-volume exposure index and between manoeuver accidents and the index. Since the index does not theoretically account for rear end accidents it was thought that a better correlation might be obtained in the second instance.

Since, as was mentioned previously, the index consists of two parameters (time and volume) it was considered instructive to investigate the effect of removing the time factor. Should the correlation between accidents and a volume-only index be as good as one containing the additional time factor, this would indicate that no additional information was being provided by the measurement of exposure times. These could then be disregarded as a viable parameter for predicting accidents. Accordingly, as before, a linear correlation coefficient was computed for accidents and volume-exposure index.

3.5.3 Accidents and Total Volumes

A rationalization similar to the above can be made with regard to simple volumes as opposed to a calculated volume index. If the correlation between accidents and volume index is no better than that between accidents and the sum of the approach volumes (from Heany - see section 2.1.2.1) then it is obvious that the more complicated index form adds nothing to the model.

Thus accidents were compared with the sums of the intersection approach volumes and a linear correlation coefficient was developed.

3.5.4 Conflicts and Time-Volume Exposure Index

As first discussed in section 2.1.1 of this report it can be said that any form of theoretical exposure index generally corresponds to the type of situations we refer to as conflicts since an accident also depends to a large extent on human reaction and vehicle mechanics.

The correlation between time-volume exposure index and conflicts was thus considered worthy of investigation.

3.5.5 Accidents and Violations

This was not considered an area likely to yield much in the way of useful results, however, since a more detailed analysis of the relationship between conflicts and violations was to be undertaken, (section 3.5.8), the correlation between accidents and violations was calculated as a matter of interest and simply as an assessment of the potential pay-off in enforcement of traffic regulations.

3.5.6 Accidents and Conflicts by Intersection

If conflicts are a valid and useful predictor for the occurrence of accidents at intersections then ultimately their desired usage would be in investigating individual intersections in order to identify problem areas and indicate solutions (as is now being studied in the U.K.)

To assess the potential of the conflicts technique in this area it is necessary to compare the distribution of accidents and conflicts at each intersection by both location and type. Normally, a chi-square test would perform this function but a review of the relevant accident data revealed that the magnitude of the numbers was, in most cases, so low as to render such a statistic suspect in terms of the validity of the results obtained. As with the data from the Pilot Study (Section 3.1.1) a rank correlation test could be performed but in doing so, much pertinent information would be lost. A procedure was therefore developed whereby the usefulness of conflicts in describing the general hazard situation by type of accident and intersection could be assessed.

Since only a relatively few intersections were analysed by location within the intersection (those investigated in the Ottawa area) it was thought best to present the results in graphical format similar to that utilized by Spicer (39). The overall efficiency of conflicts in identifying hazardous areas of an intersection can be estimated visually from the drawings.

3.5.7 Accidents and Conflicts by Time of Day

As with the information with regard to location the comparison between accidents and conflicts by time of day is best illustrated graphically. Because of expected regional and traffic pattern differences a separate plot was prepared for each of the four cities.

3.5.8 Accidents and all Variables

In order to assess the relative contribution of all the variables investigated and recorded in this study, namely, conflicts, volumes, time-volume exposure index and violations, to the prediction of accidents, a multiple regression analysis can be performed. The calculated values of accidents can now be compared with the actual values and a correlation coefficient derived. By removing variables from the analysis and repeating the process, those factors which contribute little by way of explanation of the overall accident sample variance can be eliminated thus leaving a simpler expression whose coefficient of correlation with accidents does not differ markedly from the original. Thus the final expression represents the best and simplest model which can be derived from the available data.

3.5.9 Conflicts and Violations

In addition to conflicts and violations, the study teams were instructed to record those conflicts which occurred as a direct result of some form of traffic violation. These were listed according to class of violation.

It was then possible to calculate the relative importance of each class of violation in terms of its probability of resulting in a conflict or hazard situation.

3.6 Study Results

3.6.1 Accidents and Conflicts

Accident-conflict data for all 59 intersections is summarized in Table 2. For each type of manoeuver the total accidents, conflicts and vehicular volumes (exposure) are given.

Since accidents and conflicts of the left-turn and rear end variety occur for both major and minor road traffic, these categories have been divided accordingly.

Table 3 condenses the data from Table 2 into accidents and conflicts per exposure, in this case per million opportunities. The difference between major and minor leg accident experience can easily be seen for left turn and rear end classes. While most rear end accidents occurred on the minor approaches, almost all left turn accidents involved vehicles on the main road turning across opposing traffic. This is in agreement with the results of Charlesworth and Tanner (see section 2.2.2.) and, as explained in the Appendix, had an effect on the subsequent calculation of the exposure index.

In terms of frequency of occurrence, cross-traffic accidents were by far the highest and rear end accidents the lowest. This order was found to be reflected in the total conflicts by class and in fact the rank order of accidents and conflicts is identical (rank correlation coefficient of 1.0).

TABLE 2

SUMMARY OF ACCIDENT - CONFLICT DATA

	accidents/year	conflicts*	exposure
WEAVE	34.3	314	9,847,560 35,940
RIGHT-TURN (minor legs)	11.3	323	26,371,404 96,246
CROSS TRAFFIC	249.0	2244	39,122,816 142,784
LEFT-TURN (main legs)	34.5	820	23,500,000 85,750
LEFT-TURN (minor legs)	0.80	60	19,900,000 72,742
LEFT-TURN (all legs)	35.3	880	43,426,808 158,492
REAR END (main legs)	80.0	1760	398,001,050 1,455,000
REAR END (minor legs)	23.0	260	17,753,450 62,350
REAR END (all legs)	103.0	2020	415,754,448 1,517,352

* Two 14-hr. counting days

TABLE 3

FREQUENCY OF OCCURRENCE OF ACCIDENTS AND CONFLICTS

conflict or accident situation	accidents/million opportunities	conflicts/million opportunities
weave	3.50	8,737
right-turn	0.43	3,400
cross-traffic	6.32	15,700
left-turn		
main legs	1.47	9,560
minor legs	0.04	825
all legs	0.82	5,450
rear end		
main legs	0.20	1,210
minor legs	1.30	4,160
all legs	0.25	1,340

Table 4 contains basically the same data but arranged in a slightly different format. Here the additional information given is in terms of the relative incidence of accidents to that of conflicts. It can be seen that, once again, cross-traffic manoeuvers have the highest incidence of accidents to conflicts but in this regard we find weaving situations are nearly as critical. There seems to be a sharp division between weave and cross-traffic manoeuvers at about 40 accidents per 100,000 conflicts and all the rest at 13 to 19. The fact that the ratio of rear end accidents to conflicts is similar to those for left and right turns is a indication of the omission of the precautionary class of conflicts which tend to appear mainly in the rear end data counts (see Baker, Reference 3).

Up to now we have assumed from the nature of the data, that the accident-conflict relationship is a linear one but in actual fact this may not be the case.

Considering an equation of the form

$$A = b_0 + b_1C + b_2C^2 + b_3C^3 ++++ b_nC^n$$

we can predict, from the appearance of the accident-conflict plot, that there is little point in going beyond the third order term. Accordingly the constants can be calculated by a polynomial regression fitting to arrive at the following:

$$A^* = 13.720 + 0.15825C - 0.003442C^2 + 0.0000001587C^3$$

Comparing A^* with A (the actual accident values) we obtain a correlation of 0.560 which explains about 31% of the variance.

Another possible form for the relationship to take would be that of a logarithmic plot:

$$A^* = k \log C$$

This model, however, is no improvement on the linear relationship since the net result is a correlation of 0.455 which is virtually identical to the value of 0.453 obtained in the first instance.

Figures 4 and 5 illustrate the spread of the accident-conflict data. In figure 5, the linear and polynomial relationships have been fitted to the data using least squares analysis. The coefficient of correlation obtained with the linear fit is 0.453 (Table 5) while the polynomial fit results in an improvement to 0.560 which accounts for an additional 10% of variance.

Linear correlation coefficients for all combinations of variables are summarized in Table 5 for each class of intersection. It can be seen that, in general, the coefficients for the "Tee" group are higher than for the 4-leg intersections but the small sample size negates this in terms of significance. Very few of the correlations between individual classes of accidents and conflicts are significant and most are very low, however when all intersections are grouped together these individual correlations tend to become significant at about the 5% level.

As was mentioned above, the gross linear correlation between all accidents and all conflicts for the 59 study locations was 0.453 which is significant at the 1% level. Similarly, the correlation between manoeuver accidents and conflicts (0.402) was also significant at the 1% level. This small difference between the two groupings is another indication that the observation procedures employed managed to eliminate the counting of most precautionary conflicts.

Data on accident severity were collected for a limited sample of intersections (fourteen locations in the Ottawa area) and for these intersections the more serious conflicts, that is, the manoeuver conflicts, were compared with the numbers of injury accidents. No significant correlation was evident but it should be emphasized that the size of the injury accident sample was very small.

Table 5 also shows the correlation obtained between conflicts and accidents on a volume exposure basis. Accidents per volume exposure is a more valid statistic than accidents alone since it eliminates the effects of volume differences between intersections. It can be seen that conflicts correlate extremely poorly with accidents when the data is corrected for volume exposure.

To account for variation in traffic patterns and ambient conditions by day, time and season, conflicts were also correlated with only those accidents occurring on weekdays (7a.m.-9p.m.) during the months of April to October. The correlation was not improved by this procedure, being somewhat reduced to 0.436.

TABLE 4

CONFLICT/OPPORTUNITY AND ACCIDENT/CONFLICT RATIOS

conflict - accident situation	Non Signalized 3 and 4 Legged Right-Angle Intersections	
	Conflicts per 1,000 Opportunities	Accidents per 100,000 Conflicts
Weave	8.8	39.5
Left-turn main legs	8.7	14.6
Left-turn minor legs	1.1	3.4
Left-turn all legs	5.6	14.6
Right-turn	3.4	12.8
Cross-traffic	15.7	40.5
Rear-end main legs	1.2	16.6
Rear-end minor legs	4.2	32.4
Rear-end all legs	1.3	18.7

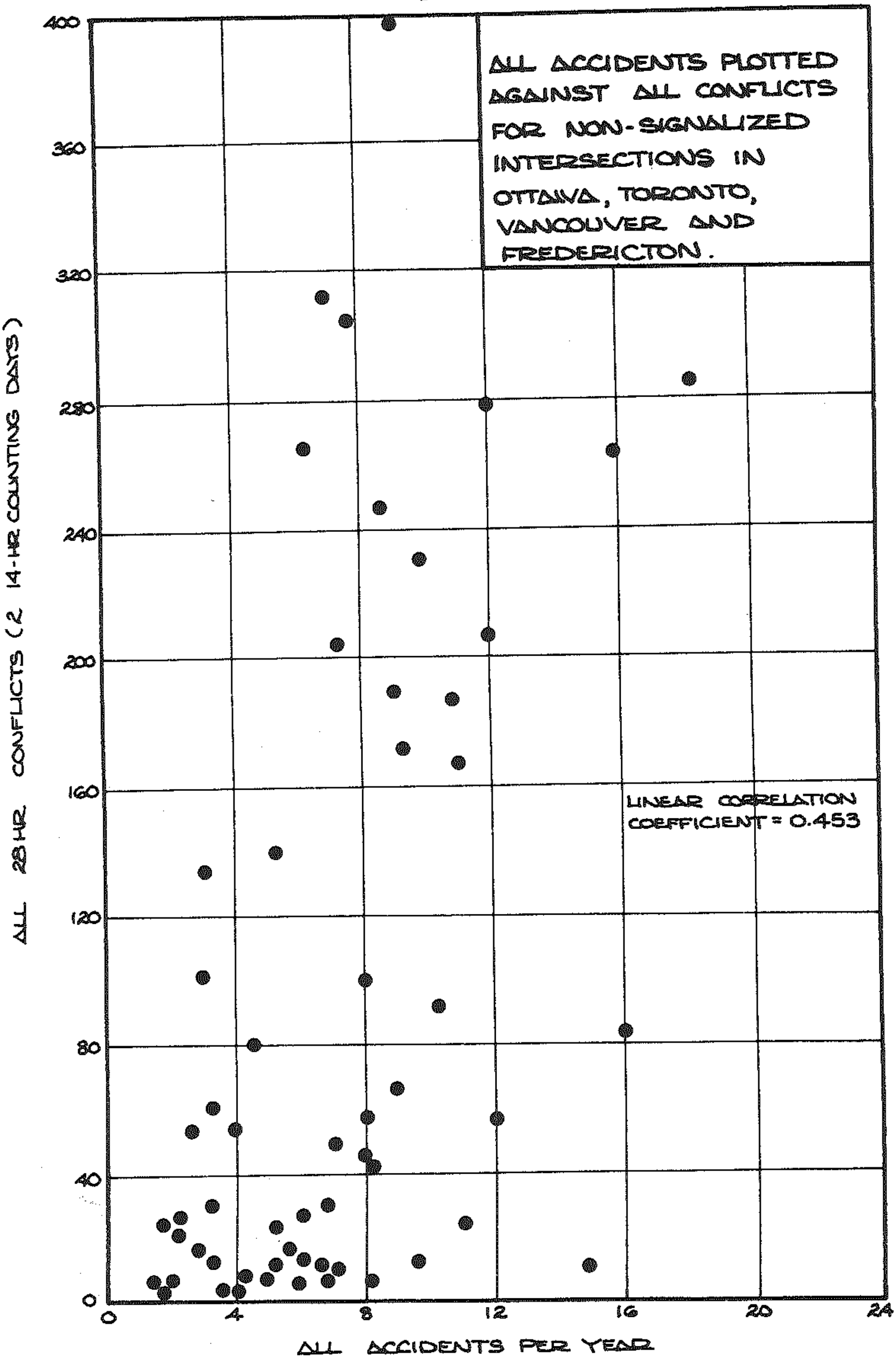
TABLE 5

LINEAR CORRELATION COEFFICIENTS BETWEEN STUDY VARIABLES

INTERSECTION GEOMETRICS

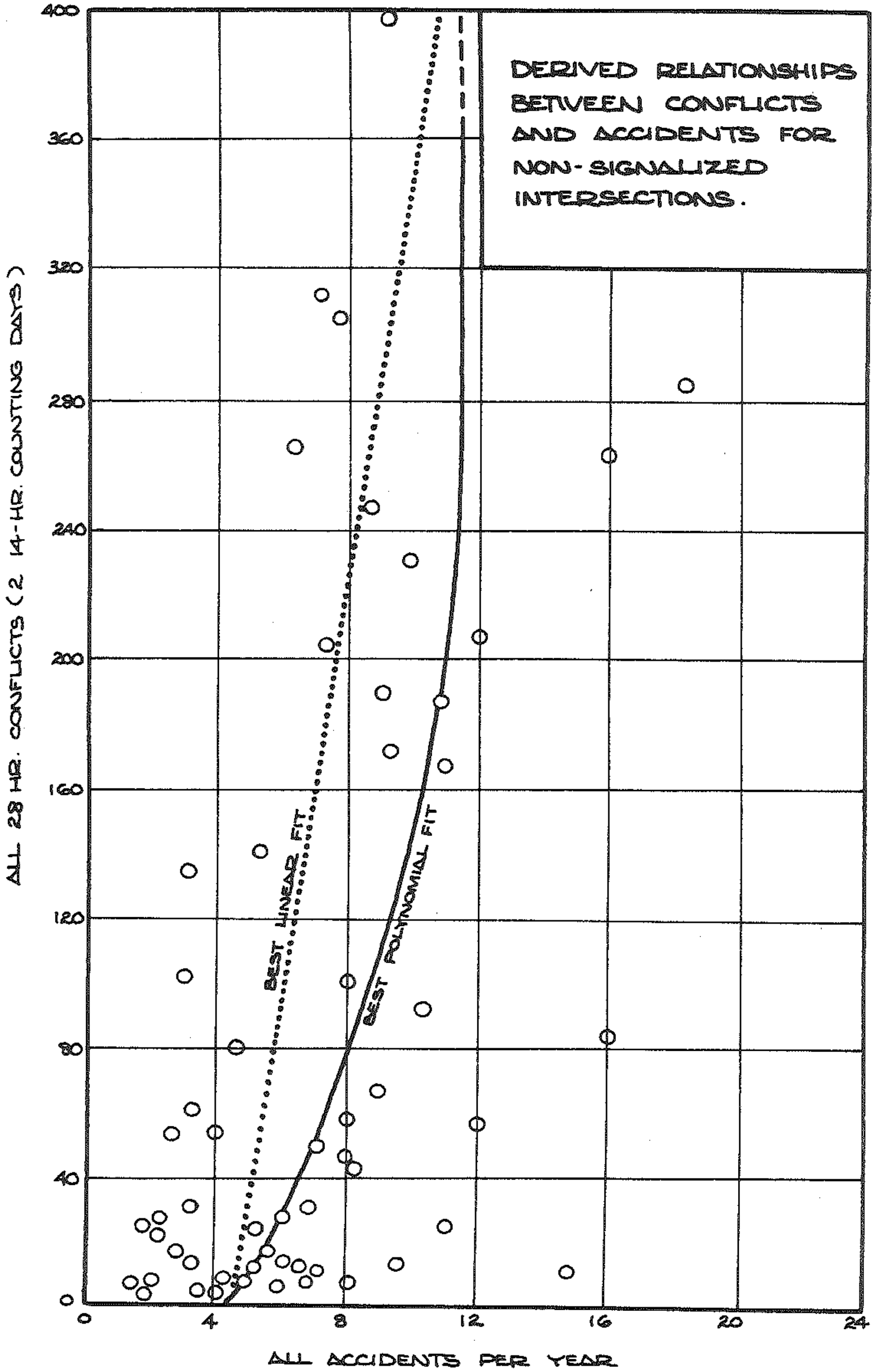
	4 leg (All 2-way)			4 leg (Two 1-way)			All 4-leg			Tee			All		
	Sample Size	Linear Correlation Coefficient	Level of Significance	Sample Size	Linear Correlation Coefficient	Level of Significance	Sample Size	Linear Correlation Coefficient	Level of Significance	Sample Size	Linear Correlation Coefficient	Level of Significance	Sample Size	Linear Correlation	Level of Significance
All Accidents vs All Conflicts	37	0.471	1%	9	-0.246	NS	46	0.407	1%	13	0.473	NS	59	0.453	1%
Manoeuver Accidents vs Manoeuver Conflicts	37	0.461	1%	9	-0.169	NS	46	0.376	5%	13	0.434	NS	59	0.402	1%
Weave Accidents vs Weave Conflicts	37	0.170	NS	9	-0.158	NS	46	0.157	NS	13	0.175	NS	59	0.220	NS
Left-Turn Accidents vs Left-Turn Conflicts	37	0.137	NS	9	0.099	NS	46	0.179	NS	13	0.480	NS	59	0.332	5%
Right-Turn Accidents vs Right-Turn Conflicts	37	0.353	5%	9	-0.183	NS	46	0.299	NS	13	0.766	1%	59	0.494	1%
Cross Traffic Accidents vs Cross Traffic Conflicts	37	0.340	5%	9	-0.143	NS	46	0.273	NS	13	0.414	NS	59	0.297	5%
Rear End Accidents vs Rear End Conflicts	37	0.133	NS	9	-0.467	NS	46	0.193	NS	13	0.434	NS	59	0.344	5%
Pedestrian Accidents vs Pedestrian Conflicts													13	0.705	1%
All Accidents vs Time-Volume Indices	37	0.682	1%	9	0.485	NS	46	0.651	1%	13	0.840	1%	59	0.620	1%
Manoeuver Accidents vs Time-Volume Indices	37	0.654	1%	9	0.445	NS	46	0.587	1%	13	0.798	1%	59	0.488	1%
All Conflicts vs Time-Volume Indices	37	0.587	1%	9	-0.062	NS	46	0.587	1%	13	0.474	NS	59	0.503	1%
Manoeuver Conflicts vs Time-Volume Indices	37	0.638	1%	9	-0.034	NS	46	0.629	1%	13	0.686	1%	59	0.582	1%
All Accidents vs Total Volumes	37	0.704	1%	9	0.380	NS	46	0.653	1%	13	0.671	5%	59	0.670	1%
Time-Volume Indices vs Total Volumes													59	0.685	1%
Volume Indices (without time factor) vs Accidents	37	0.657	1%	9	0.516	NS	46	0.617	1%	13	0.615	5%	59	0.569	1%
All Accidents vs Violations	37	0.137	NS	9	-0.067	NS	46	0.098	NS	13	-0.004	NS	59	0.098	NS
All Conflicts vs. Total Volumes													59	0.570	1%
All Accidents/Volume vs. All Conflicts/Volume													59	-0.078	NS
All Accidents/Volume vs. Total Volumes													59	-0.357	5%
All Accident/Volume vs. Time - Volume Indices													59	-0.175	NS
All Accidents (Weekdays, 7 am - 9 pm, April-Oct.) vs All Conflicts													59	0.436	

FIGURE 4



ALL ACCIDENTS PLOTTED AGAINST ALL CONFLICTS FOR NON-SIGNALIZED INTERSECTIONS IN OTTAWA, TORONTO, VANCOUVER AND FREDERICTON.
LINEAR CORRELATION COEFFICIENT = 0.453
ALL 28 HR CONFLICTS (2 14-HR COUNTING DAYS)
ALL ACCIDENTS PER YEAR
0
40
80
120
160
200
240
280
320
360
400
4
8
12
16
20
24

FIGURE 5


DERIVED RELATIONSHIPS BETWEEN CONFLICTS AND ACCIDENTS FOR NON-SIGNALIZED INTERSECTIONS.
BEST LINEAR FIT
BEST POLYNOMIAL FIT
ALL 28 HR. CONFLICTS (2 14-HR. COUNTING DAYS)
0
40
80
120
160
200
240
280
320
360
400
0
4
8
12
16
20
24
ALL ACCIDENTS PER YEAR

Since average through speeds at the intersections varied from about 15 to 50mph., the data were separated into two groups by speed: above the median (25mph) and below. Conflict-accident correlations within these two groups were 0.417 and 0.465 respectively which did not indicate any effect of travel speed on the statistic.

3.6.2 Accidents and Time-Volume Exposure Index

Table 5 shows the linear correlation coefficients which were calculated for accidents vs the time-volume exposure index for the various classes of intersection. Figures 6 and 7 illustrate the results graphically. It can be seen that, at a coefficient of 0.620, the time-volume index represents a significant improvement over conflicts when all the locations are considered together, and also for each type of junction design. A similar situation is also apparent when the data are considered by city. Table 6 presents a comparison of data from the four study areas and here again, correlation coefficients for the time-volume index are consistently highly than those for conflicts.

In order to assess the contribution of the time factor in the index, a separate index was calculated which was identical to the time-volume calculation but omitted the exposure times. This volume-only exposure index was correlated with accidents and linear coefficients were calculated. From Table 5 the relative efficiency of the two indices can be compared with the result that the time-volume index appears to be consistently a better accident predictor model. This can also be seen in the reduced scatter of data in Figure 9 as compared to Figure 8. It would therefore seem that the consideration of exposure time can provide significant additional information.

Average through vehicle speeds were calculated from exposure times for each intersection but no correlation was found between these speeds and the accident rates per unit volume exposure.

FIGURE 6

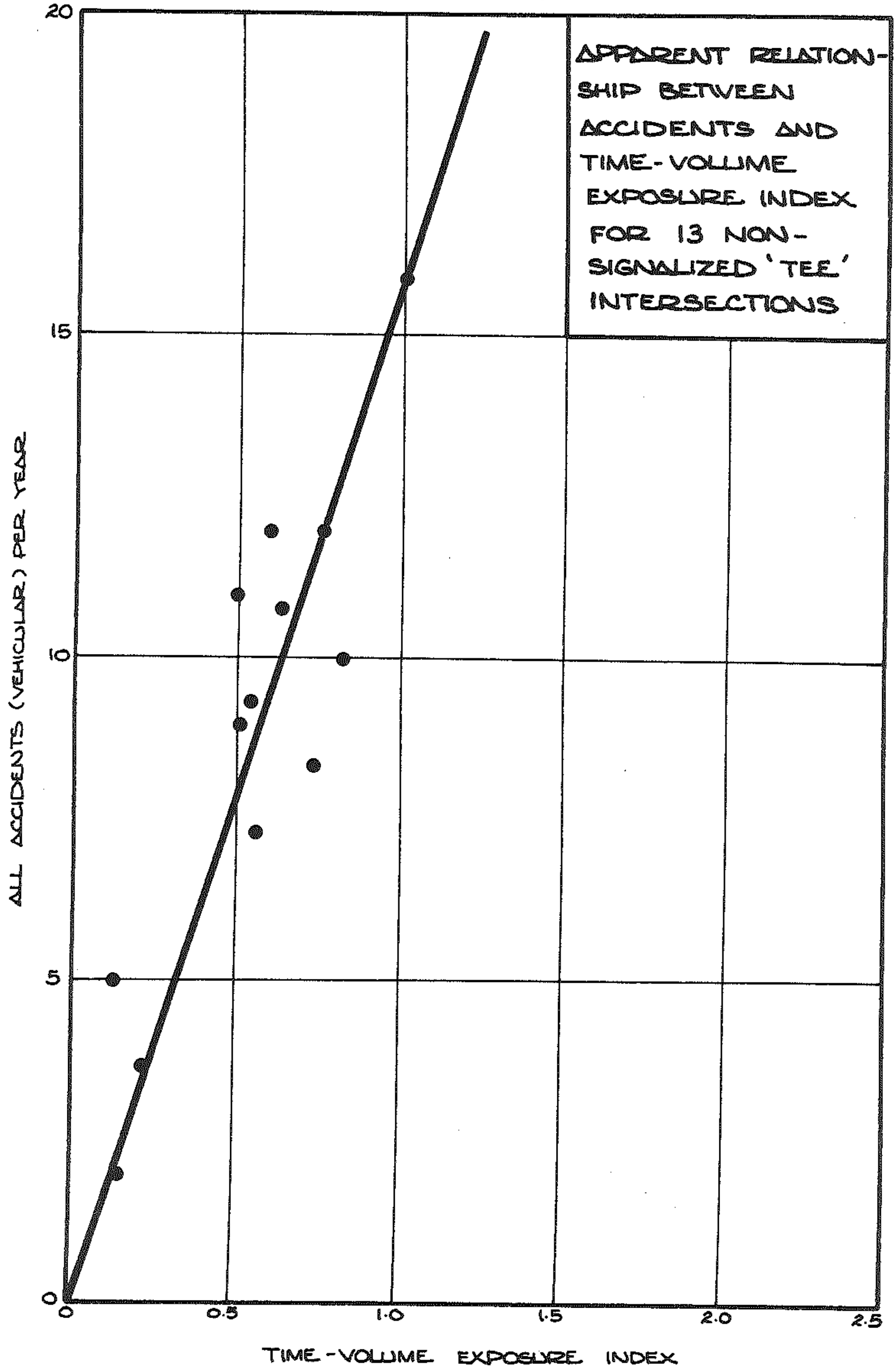
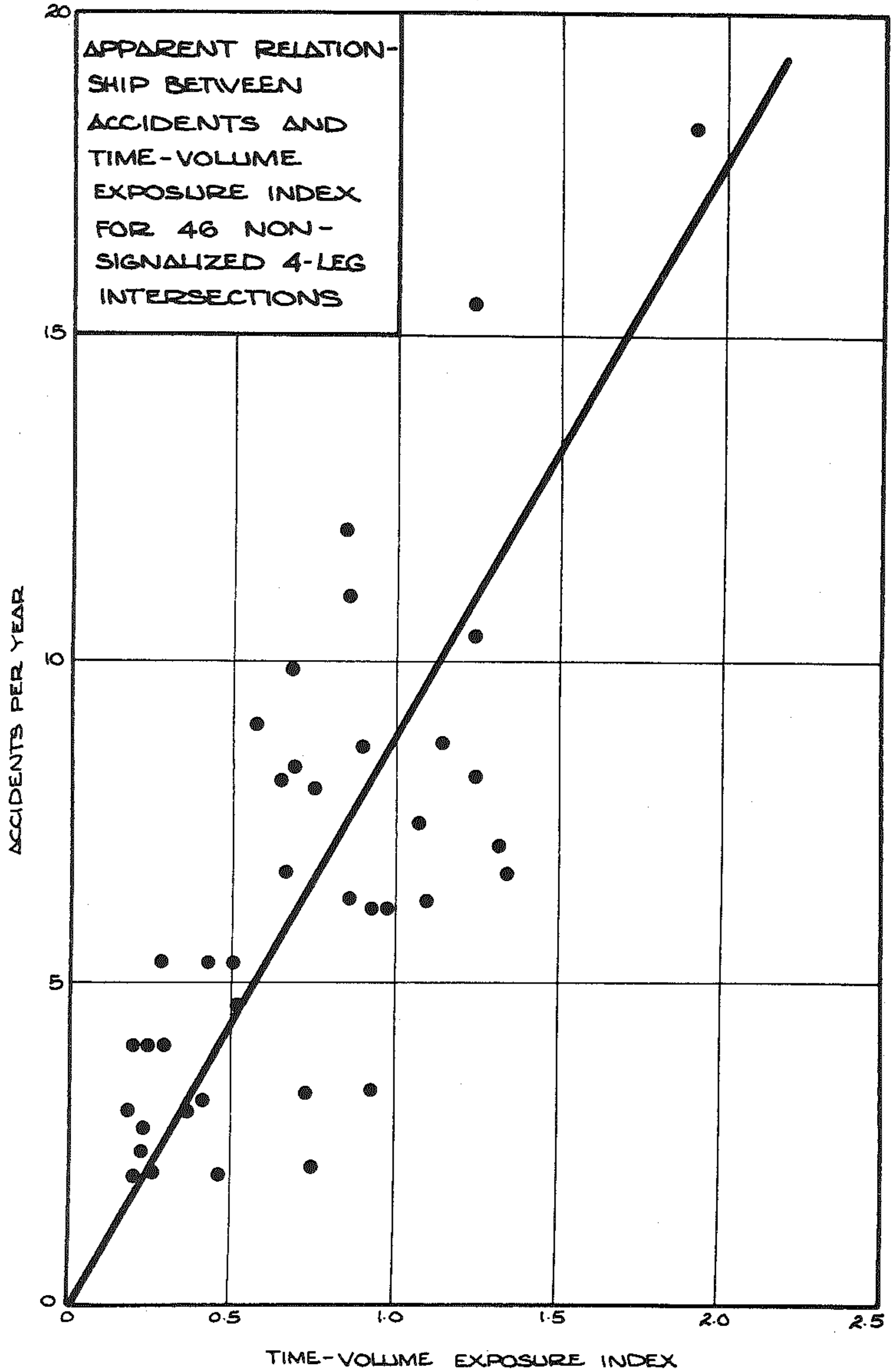

APPARENT RELATIONSHIP BETWEEN ACCIDENTS AND TIME-VOLUME EXPOSURE INDEX FOR 13 NON-SIGNALIZED 'TEE' INTERSECTIONS
20
15
10
5
0
ALL ACCIDENTS (VEHICULAR) PER YEAR
0
0.5
1.0
1.5
2.0
2.5
TIME-VOLUME EXPOSURE INDEX

FIGURE 7



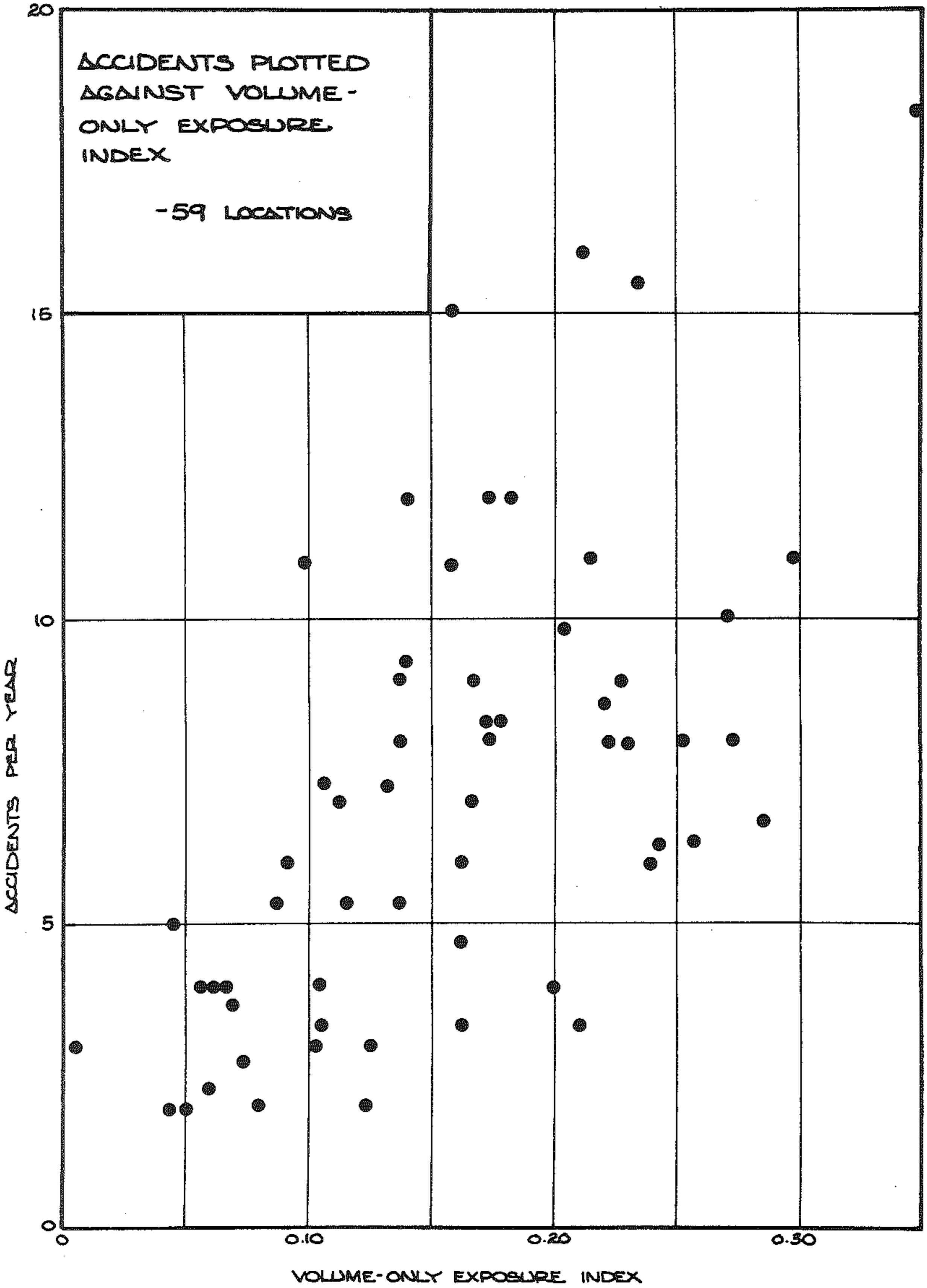
APPARENT RELATIONSHIP BETWEEN ACCIDENTS AND TIME-VOLUME EXPOSURE INDEX FOR 46 NON-SIGNALIZED 4-LEG INTERSECTIONS
ACCIDENTS PER YEAR
20
15
10
5
0
0
0.5
1.0
1.5
2.0
2.5
TIME-VOLUME EXPOSURE INDEX

TABLE 6

COMPARISON OF DATA FROM 4 CITIES

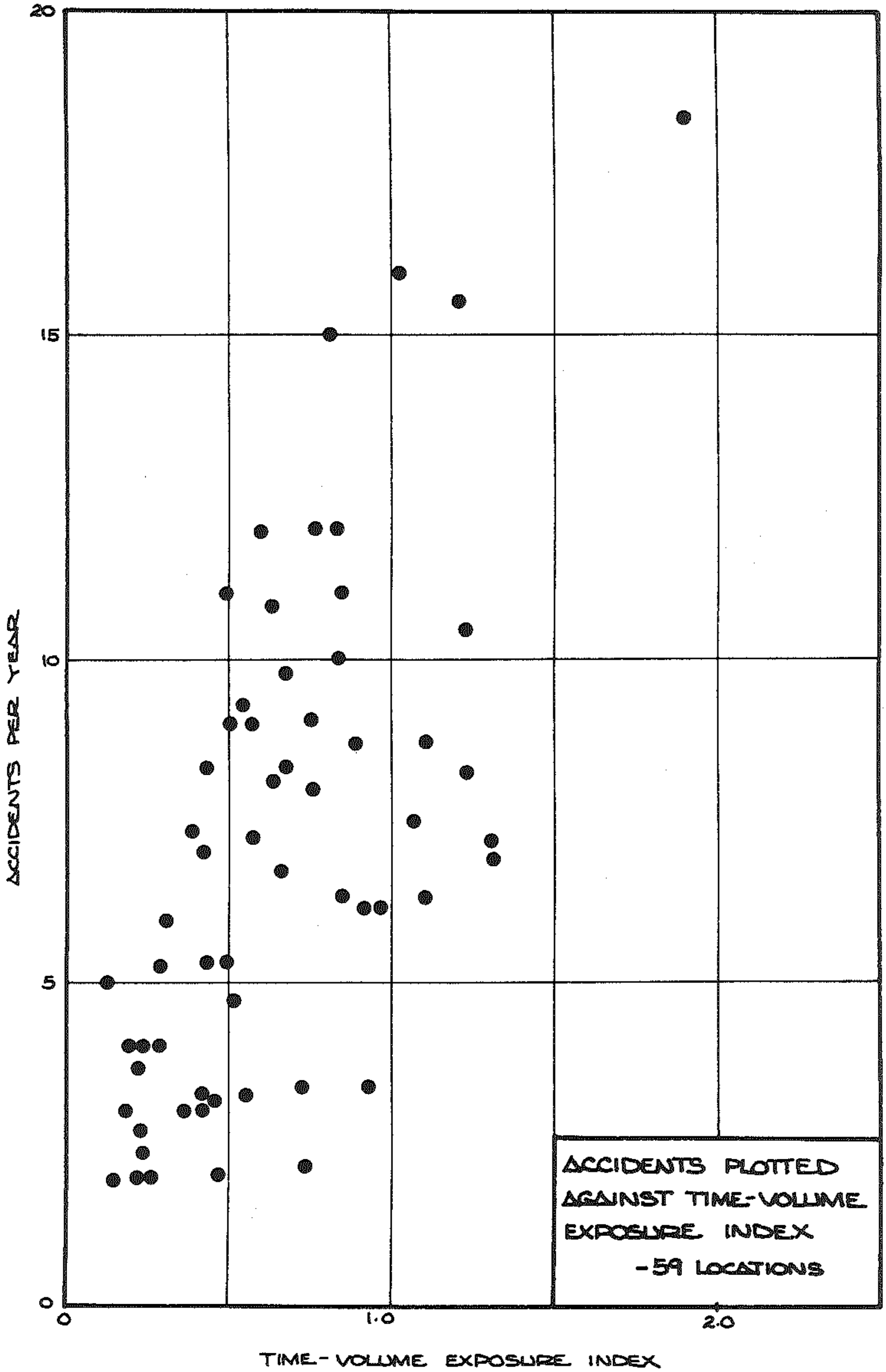
	Linear correlation coefficients		
City	accidents vs conflicts	accidents vs volumes	accidents vs time volume index.
Vancouver	0.334	0.538	0.617
Toronto	0.250	0.392	0.533
Fredericton	0.264	0.378	0.489
Ottawa	0.401	0.548	0.817

FIGURE 8



ACCIDENTS PLOTTED AGAINST VOLUME-ONLY EXPOSURE INDEX
-59 LOCATIONS
20
15
10
5
0
0
0.10
0.20
0.30
ACCIDENTS PER YEAR
VOLUME-ONLY EXPOSURE INDEX

FIGURE 9


20
15
10
5
0
ACCIDENTS PER YEAR
0
1.0
2.0
TIME-VOLUME EXPOSURE INDEX
ACCIDENTS PLOTTED AGAINST TIME-VOLUME EXPOSURE INDEX
-59 LOCATIONS

3.6.3 Accidents and Total Volumes

The simple sum of approach volumes is perhaps the most commonly employed form of accident-predictor model and is certainly the easiest to use. It was expected, however, (23,8), that an index employing a detailed volume cross-product analysis for each conflicting manoeuver would improve the model. Table 5, especially where results are shown for all intersections grouped together, indicates a surprising result. For the total sample of intersections in this study the best accident prediction was obtained using the simple sum of approach volumes.

While this was indeed the case it should be noted that the correlation between accidents and time-volume index was only marginally inferior for all locations and was considerably better when only "Tee" intersections were considered, and also for individual cities (Table 6).

Also, a survey of the data indicates that the use of total volume summations cannot account for individual cases where the accident record is inexplicably high or low and also cannot distinguish between intersections of similar volume usage but widely differing accident histories. In Table 7, a number of intersections have been grouped according to geographical area, geometric similarity and volume usage so that none of these factors can account for the resulting differences in accidents experienced at the locations. It can be seen that while conflicts are relatively inefficient at explaining the existence of these differences, the time-volume index fails in only one case out of eight to provide a correct distinction.

3.6.4 Conflicts and Time-Volume Exposure Index

Since the calculated exposure index was based on an analysis of conflicting vehicle manoeuvers there should intuitively be a good relationship with conflicts themselves, however, as Table 5 indicates, this was not the case. In fact, the correlations obtained were inferior to those relating accidents and the index. No explanation, except for the inherent uncertainty of the definition and counting of the conflicts, can be advanced.

3.6.5. Accidents and Violations

The data on accidents and violations is summarized in Table 8. In general it can be said that there was no correlation (0.098 for all cities) although for twelve locations in Vancouver the relationship was very good.

TABLE 7

COMPARISON OF SIMILAR INTERSECTIONS IN THE VARIOUS CITIES WHICH HAVE DIFFERENT ACCIDENT HISTORIES AND THE ABILITY OF CONFLICTS AND TIME-VOLUME INDEX TO EXPLAIN THESE DIFFERENCES.

Location	Volume	Accidents	Conflicts	Explain difference	Index	Explain differenc
OTTAWA	10,398	6	7	YES	.261	YES
4-leg	10,674	18	22		.287	
	42,012	21	204		.582	
3-leg	43,396	24	42	NO	.740	YES
	44,426	37	279		.780	
FREDERICTON	10,958	7	21	NO	.213	YES
4-leg	10,342	12	2		.296	
4-leg	17,098	6	6	YES	.468	YES
	17,756	14	79		.502	
TORONTO	25,742	6	5	YES	.757	YES
4-leg	25,178	25	15		.916	
VANCOUVER	29,906	24	268	NO	.850	NO
4-leg	30,476	32	188		.843	
4-leg	32,790	24	554	NO	1.11	YES
	32,032	36	248		1.15	
4-leg	42,130	56	314	NO	1.21	YES
	43,658	62	285		1.90	

TABLE 8

RELATIONSHIPS BETWEEN ACCIDENTS AND VIOLATIONS FOR 59 NON-SIGNALIZED INTERSECTIONS

Variable Groupings	Linear Correlation Coefficient	Significant at 5% Level
All accidents vs All violations		
- Vancouver	+0.854	Yes
- Toronto	-0.170	No
- Fredericton	+0.264	No
- Ottawa	-0.012	No
- All cities	+0.098	No
% weave accidents vs % weave violations	+0.090	No
% manoeuver accidents vs % crossing violations*	+0.043	No

*All violations minus failure to signal turns

Violations will be discussed in more detail in a later section but it would appear from the above results that, in a gross sense at any rate, high incidence of violations is not necessarily related to high accident record. The explanation may be forthcoming from a detailed analysis of individual violations and resulting conflicts which is attempted in section 3.6.9

3.6.6. <u>Accidents and Conflicts by Intersection</u>

Conflicts and accidents have been analysed by location within the intersection for a sample of six junctions in the Ottawa area. The results are presented in diagrammatic form in Figures 10 through 12. In general it can be seen that the intersection areas where the majority of conflicts occur are also those to which the greatest proportion of accidents are attributed (although only one rank correlation coefficient is significant at the 5% level). This is in agreement with the work of Spicer (39) in Great Britain and seems to indicate one useful application of the conflicts technique.

Table 9 represents an attempt to assess the efficiency of conflicts in predicting accidents by type and vehicle manoeuver while Table 10 illustrates a similar application of the time-volume exposure index.

To construct Table 9, the 59 intersections were separated into groups which were defined by the major contributing conflict type. Rear end and cross-traffic categories were singled out since they represented, in most cases, the most numerous data. The intersections were then checked for their corresponding accident distributions in order to evaluate the ability of the conflict groupings to predict or account for the actual distribution of accidents.

The table indicates the heavy concentration of cross-traffic accident intersections which was found to be characteristic of the study dealing, as it did, with non-signalized locations (an intersection was arbitrarily defined as being in the cross-traffic group if conflicts or accidents of the other types each amounted to less than one-third of those classified as cross-traffic). By looking at the numbers on the diagonal which indicate the percentage correspondence between similar groupings of accidents and conflicts, it can be seen that, with the exception of the cross-traffic group, all the percentages are low thereby indicating poor correlation.

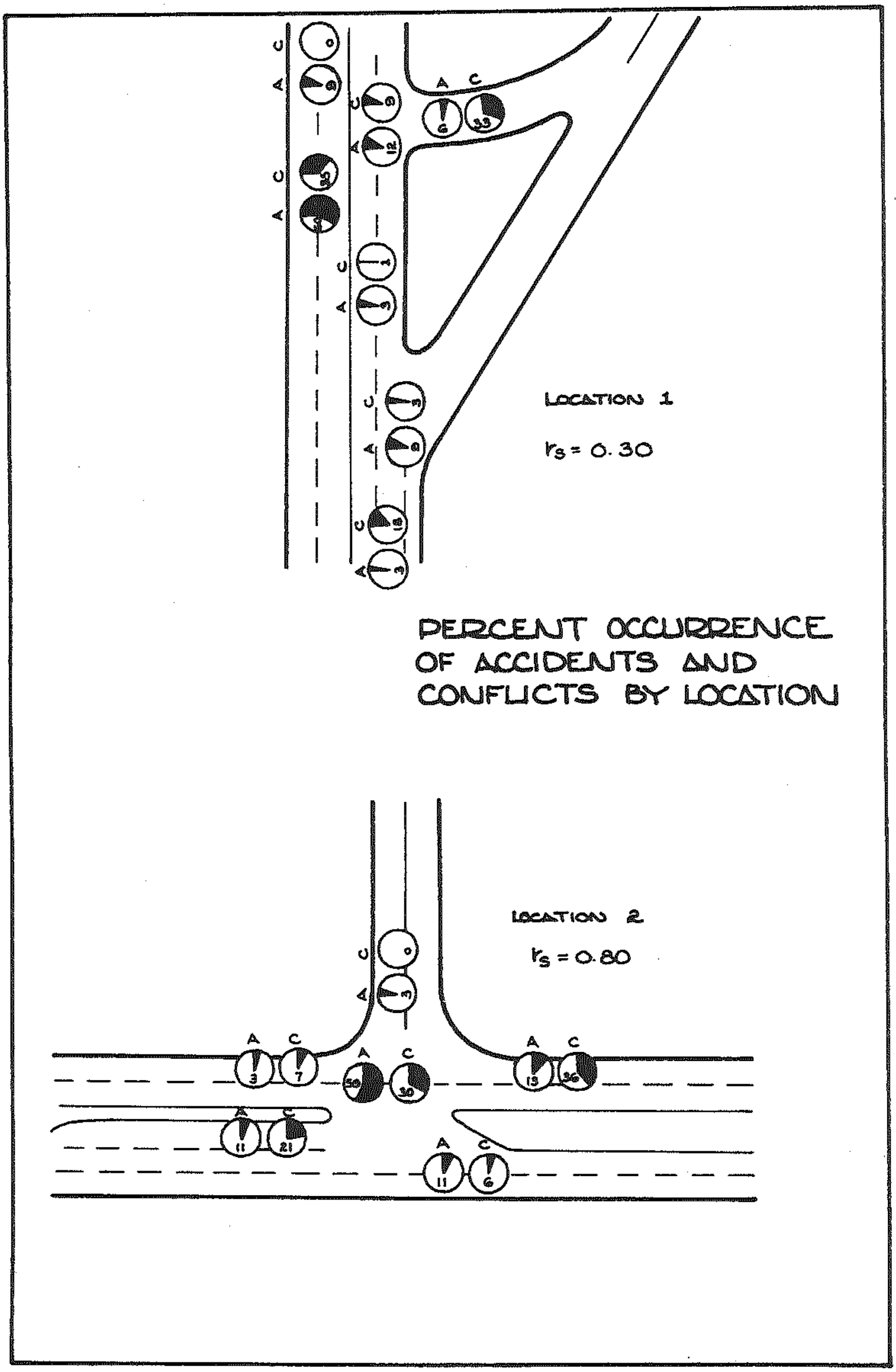
Since the time-volume index is based on a volume cross-product, such incidents as rear-end and weave cannot easily be modelled. In developing a similar matrix to the one described above for conflicts and accidents, therefore, one is restricted to four groupings, only three of which contained sufficient data for analysis. Such a matrix has been reproduced at the bottom of Table 10 in order to facilitate comparison with Table 9. The primary part of Table 10 compares three major groupings of accidents and indices for high accident locations where sufficient data are available.

Due to the relatively small amount of data in many of the categories of both indices and conflicts, the performance of a statistical test (such as a chi-square test) would be meaningless. It can only be said, with reference to Tables 9 and 10, that, on an individual intersection basis, conflicts did not constitute a good or reliable predictor of accidents and, while the time-volume index appeared to perform somewhat better, it is obviously insufficient in its present form or concept.

One more possible use for the conflicts technique, that of simply identifying whether or not a particular intersection is hazardous in comparison with others of similar volume usage, is illustrated in Figure 13. While conflicts and volume together can, in a general sense, indicate high or low numbers of total accidents to be anticipated (3.6.8 and Table 5) this is not a true indication of hazard since it takes no account of exposure. Figure 13 shows no discernable predictive trend associated with conflicts within various ranges of volume. In other words, given a group of intersections within a certain volume range, it was impossible to determine, through the use of conflicts alone, which locations had an accident history above the median rate per vehicle and which had one below.

It is interesting to note from the graph that the major concentration of high accident rate intersections is in the low volume ranges and vice versa. The high accident rate group in the low volume ranges consists of all the rural intersections studied (seven) with the remainder being minor urban or sub-urban four-leg junctions. While funds for remedial action are often first allocated to high volume, high accident locations, it may well be that an overall greater benefit would be achieved by concentrating on the lower volume hazardous intersections where remedial measures will generally be less costly and the cost-effectiveness higher.

FIGURE 10



LOCATION 1
$r_s = 0.30$
PERCENT OCCURRENCE OF ACCIDENTS AND CONFLICTS BY LOCATION
LOCATION 2
$r_s = 0.80$

FIGURE 11

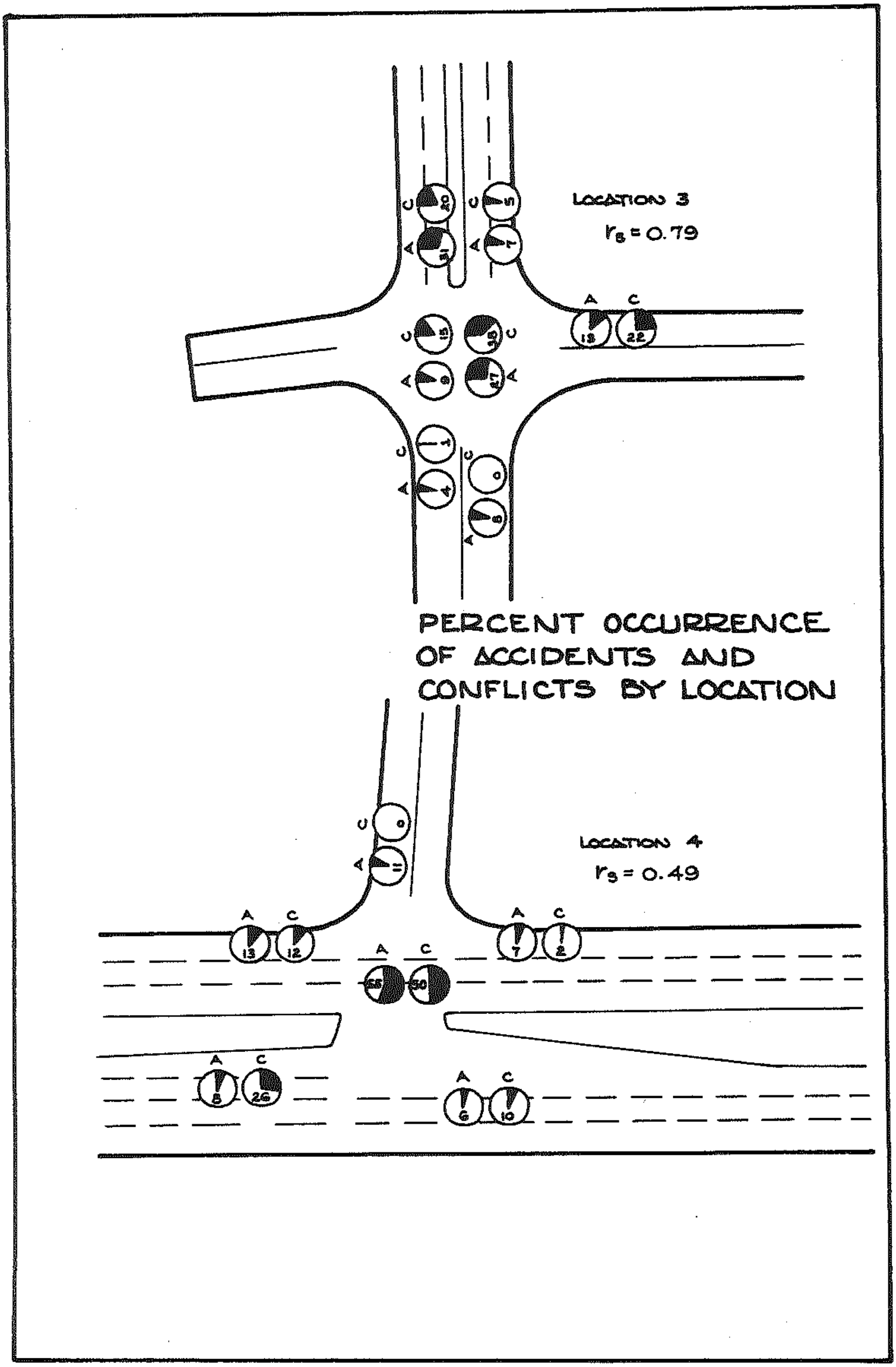
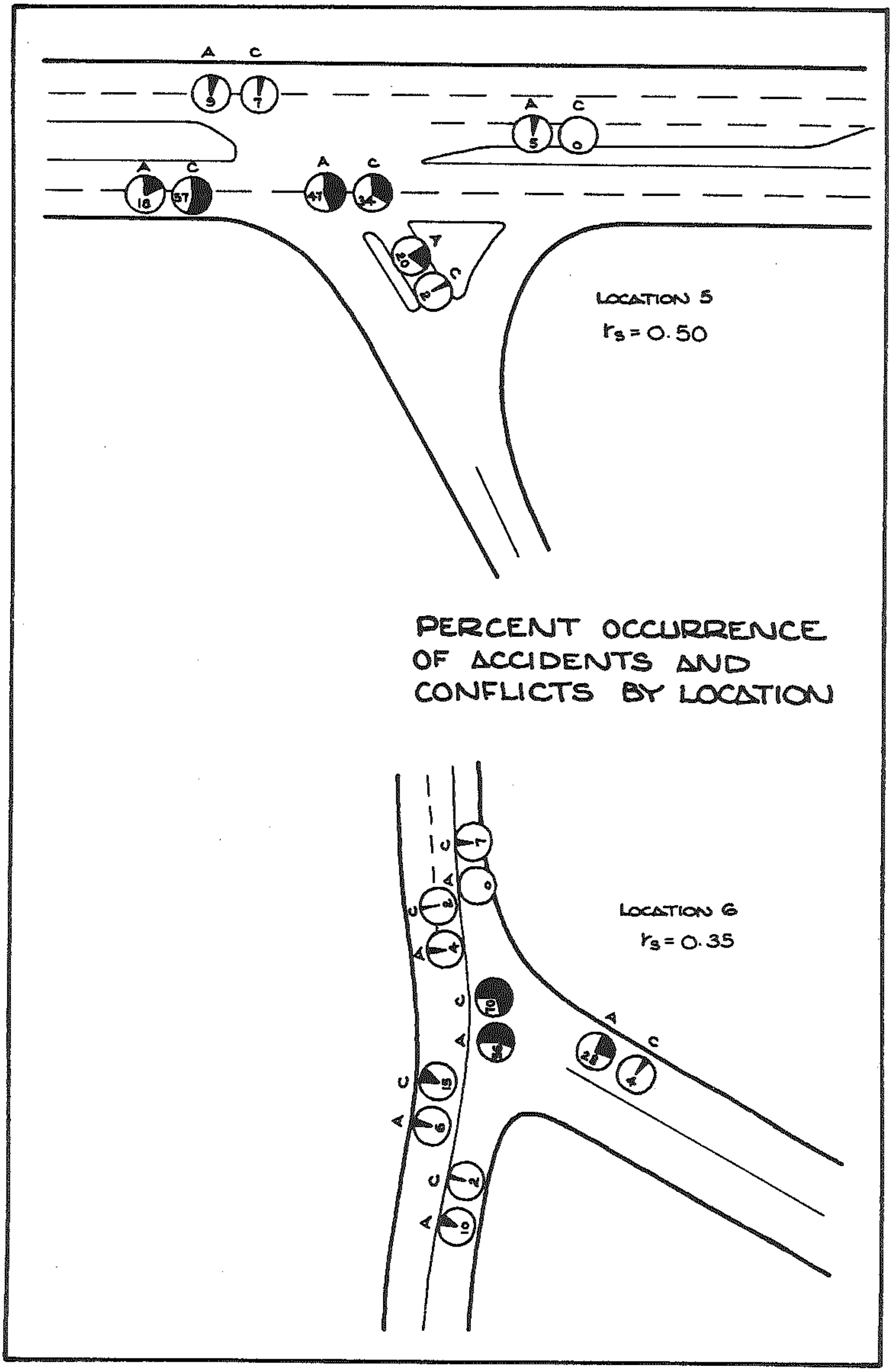

LOCATION 3
$r_s = 0.79$
PERCENT OCCURRENCE OF ACCIDENTS AND CONFLICTS BY LOCATION
LOCATION 4
$r_s = 0.49$

FIGURE 12



A
C
9
7
A
C
5
0
A
C
18
57
A
C
47
34
A
20
C
2
LOCATION 5
$r_s = 0.50$
PERCENT OCCURRENCE OF ACCIDENTS AND CONFLICTS BY LOCATION
C
7
A
0
C
2
A
4
C
10
A
36
A
C
28
4
C
15
A
6
C
2
A
10
LOCATION 6
$r_s = 0.35$

TABLE 9

DISTRIBUTION OF INTERSECTIONS BY TYPE OF CONFLICT OR ACCIDENT

- BY PERCENT IN EACH CATAGORY OF CONFLICT

CONFLICTS

ACCIDENTS	MAINLY CROSS-TRAFFIC	MAINLY CROSS-TRAFFIC AND REAR END	MAINLY REAR END	ALL TYPES CONTRIBUTE EQUALLY	MAINLY WEAVE, LEFT TURN OR RIGHT TURN
MAINLY CROSS-TRAFFIC	63	70	55	54	0
MAINLY CROSS-TRAFFIC AND REAR END	37	26	0	15	75
MAINLY REAR END	0	0	9	8	25
ALL TYPES CONTRIBUTE EQUALLY	0	4	36	23	0
MAINLY WEAVE, LEFT TURN OR RIGHT TURN	0	0	0	0	0

TABLE 10

EFFICIENCY OF TIME-VOLUME INDEX IN EXPLAINING
THE DISTRIBUTION OF ACCIDENTS BY TYPE AT
INDIVIDUAL HIGH-ACCIDENT LOCATIONS

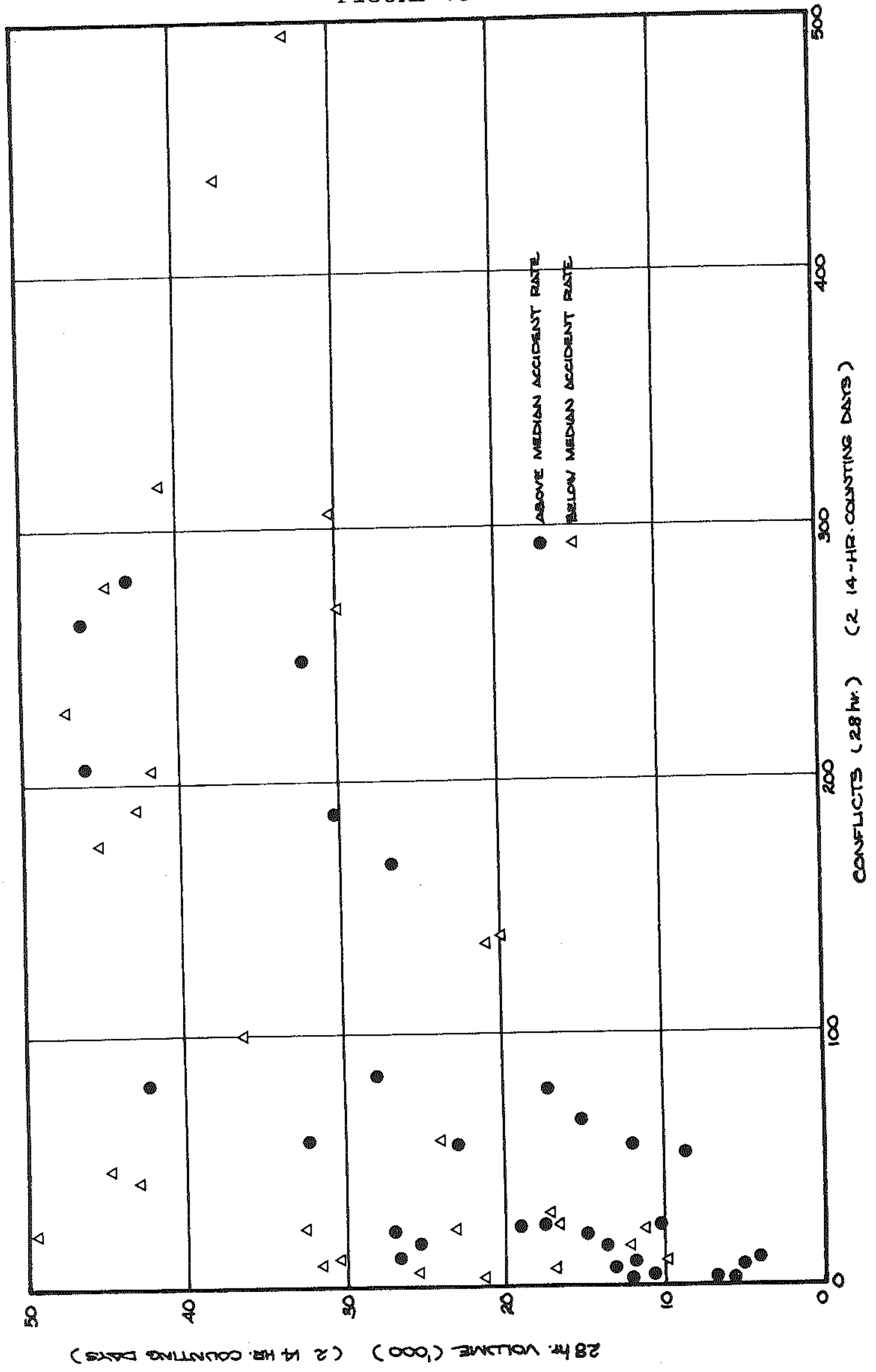
Manoeuver Accidents (%)			Time-Volume Index (%)		
cross-traffic	left turn	right turn	cross-traffic	left turn	right turn
84.5	15.5	0	65.2	21.1	13.7
88.0	9.5	2.5	51.1	38.4	11.5
58.3	37.5	4.2	48.7	45.9	5.4
76.9	7.7	15.4	59.7	9.2	31.1
81.4	11.1	7.5	68.4	17.4	14.2
70.0	10.0	20.0	42.9	26.5	30.6
62.5	25.0	12.5	40.5	34.6	24.9
88.0	12.0	0	43.0	35.5	21.5
91.3	0	8.7	68.0	16.6	15.4
88.2	5.9	5.9	58.2	29.6	12.2
76.9	7.7	15.4	35.1	34.4	30.5
50.0	40.0	10.0	18.8	48.0	33.2

PERCENT OF LOCATIONS BY MAJOR CONTRIBUTION TO TIME-VOLUME INDEX

ACCIDENTS \ INDEX	MAINLY CROSS-TRAFFIC	CROSS-TRAFFIC AND LEFT TURN	ALL
MAINLY CROSS-TRAFFIC	90	54	58
CROSS-TRAFFIC AND LEFT TURN	0	18	6
ALL	10	28	36

FIGURE 13

ACCIDENTS PER UNIT VOLUME AS A FUNCTION OF CONFLICTS AND TOTAL VOLUMES



3.6.7. Accidents and Conflicts by Time of Day

Figures 14 to 18 represent hourly plots of accidents and conflicts by time day (7 a.m. to 8 p.m.). Data from each city have been treated separately in recognition of the variation in traffic patterns and resulting volume peaks (accidents have often been shown to follow roughly the fluctuations in the time-volume plot and such was also found to be the case in this study).

In general, the correspondence between accidents and conflicts by time of day is fairly close, especially in the larger cities such as Toronto which probably have more pronounced peak flow periods. The combined data from all four cities indicates coincidence of major peaks for accidents and conflicts at 8 a.m. and 4-5 p.m., the latter being by far the most prominent. The early peak occurring for the afternoon rush is due to the fact that the study was carried out in the summer months when special summer hours were normally in effect.

3.6.8 Accidents and All Variables

In the collection of data at intersections, four different variables were recorded or later calculated. These were:

1. Conflicts (C)
2. Violations (V)
3. Total approach volumes (v)
4. Time-volume exposure index (E)

To test the independence of the variables we can calculate the applicable partial correlations according to the formulae:

$$r_{12.3} = \frac{r_{12} - r_{13.}\, r_{23}}{\sqrt{1 - r_{13}^2}\,\sqrt{1 - r_{23}^2}} \qquad R_{1.23} = \sqrt{\frac{r_{12}^2 + r_{13}^2 - 2r_{12}\, r_{13}\, r_{23}}{1 - r_{23}^2}}$$

FIGURE 14

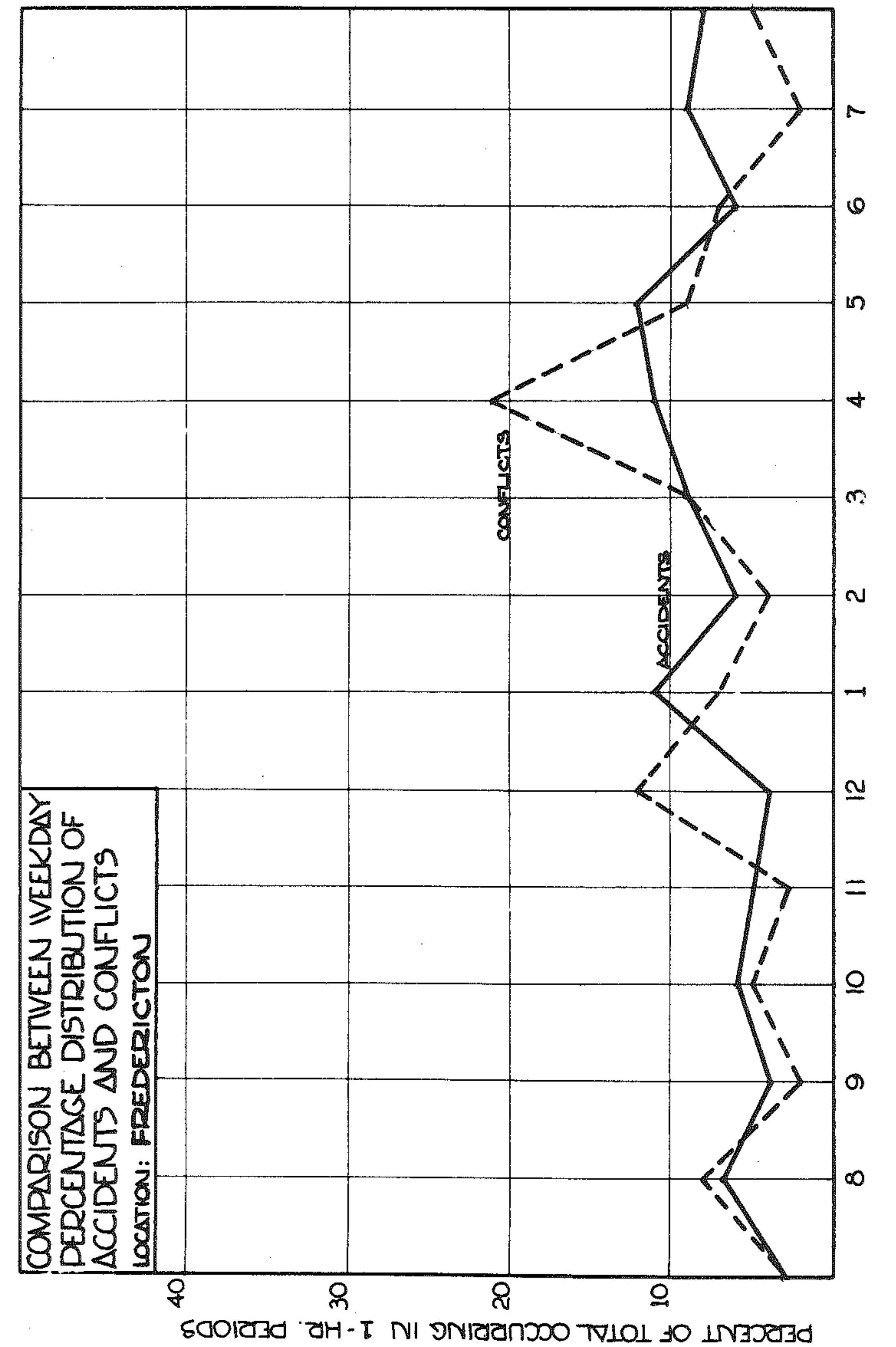
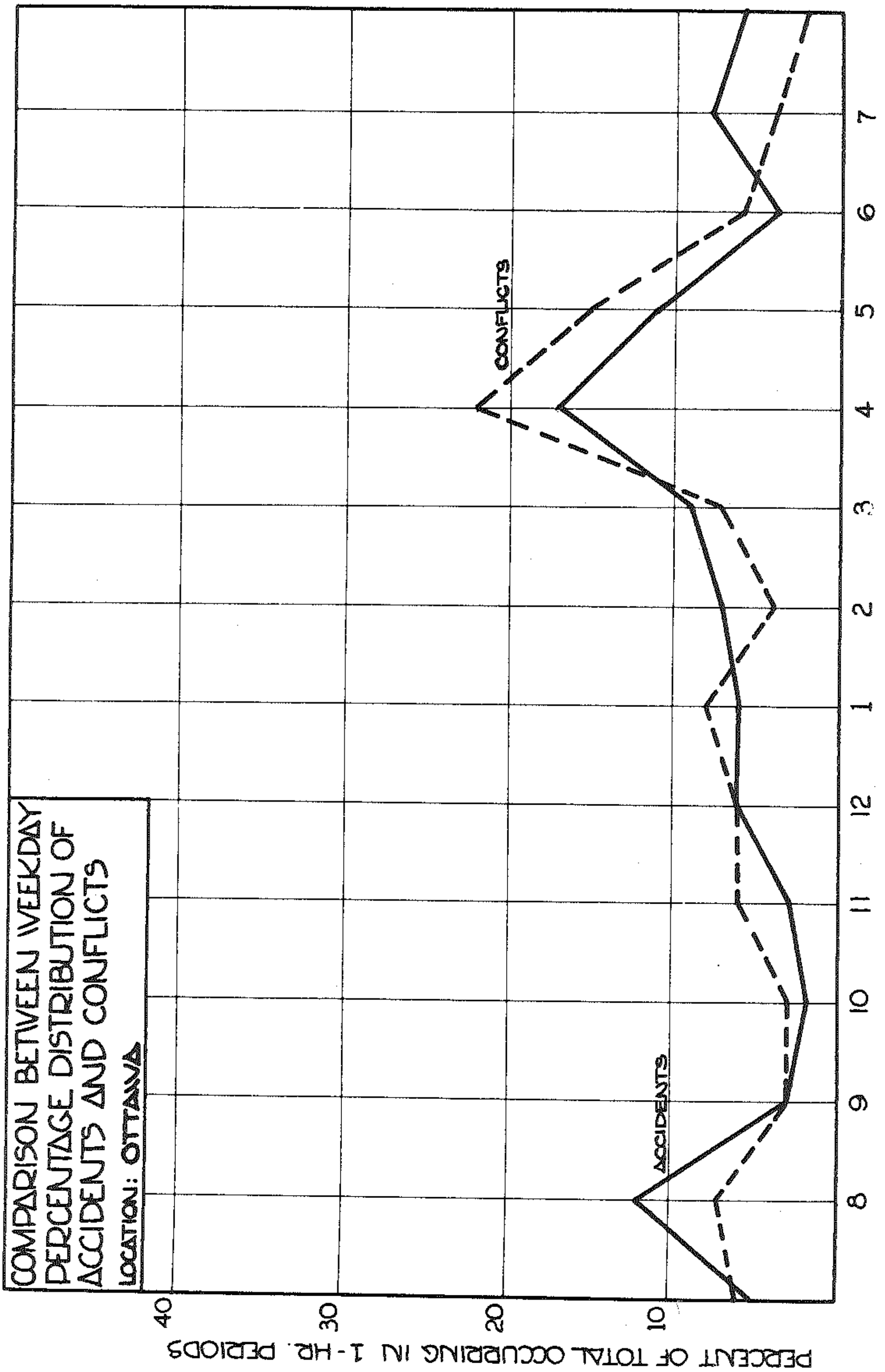
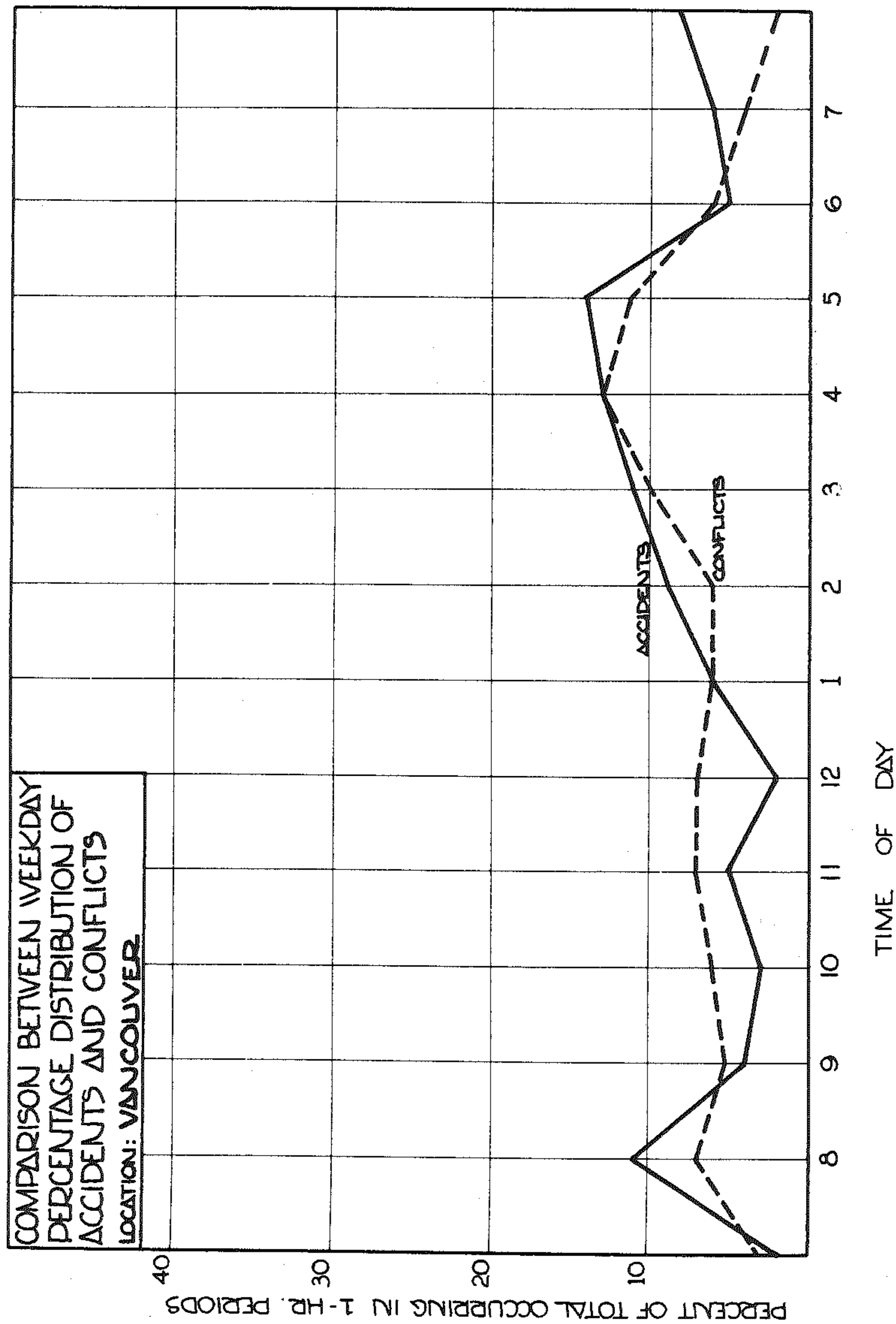

COMPARISON BETWEEN WEEKDAY PERCENTAGE DISTRIBUTION OF ACCIDENTS AND CONFLICTS
LOCATION: FREDERICTON
CONFLICTS
ACCIDENTS
40
30
20
10
PERCENT OF TOTAL OCCURRING IN 1-HR. PERIODS
8
9
10
11
12
1
2
3
4
5
6
7
TIME OF DAY

FIGURE 15



COMPARISON BETWEEN WEEKDAY PERCENTAGE DISTRIBUTION OF ACCIDENTS AND CONFLICTS
LOCATION: OTTAWA
ACCIDENTS
CONFLICTS
40
30
20
10
PERCENT OF TOTAL OCCURRING IN 1-HR. PERIODS
8
9
10
11
12
1
2
3
4
5
6
7
TIME OF DAY

FIGURE 16



COMPARISON BETWEEN WEEKDAY PERCENTAGE DISTRIBUTION OF ACCIDENTS AND CONFLICTS
LOCATION: VANCOUVER
ACCIDENTS
CONFLICTS
40
30
20
10
PERCENT OF TOTAL OCCURRING IN 1-HR. PERIODS
8
9
10
11
12
1
2
3
4
5
6
7
TIME OF DAY

FIGURE 17

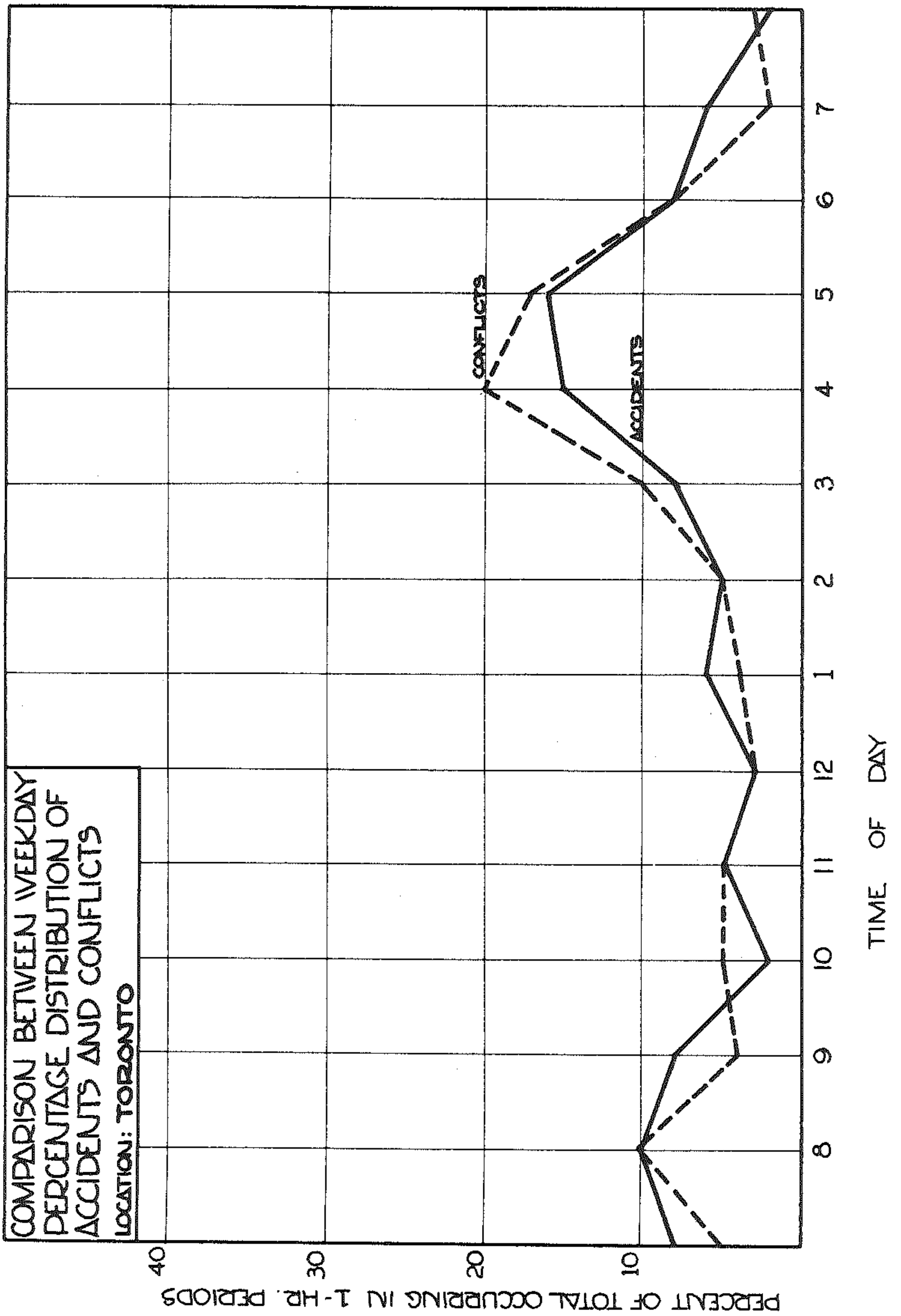
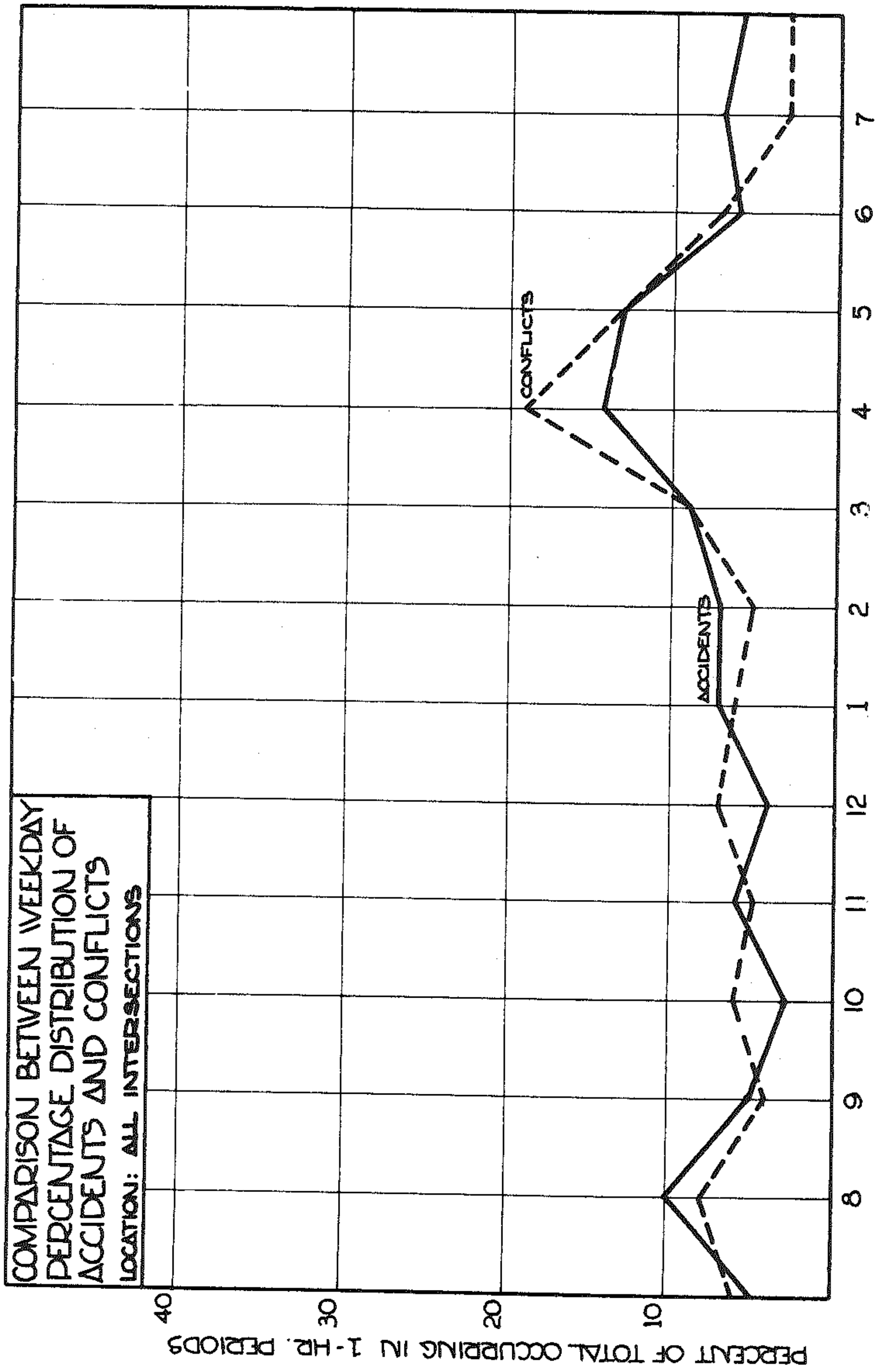

COMPARISON BETWEEN WEEKDAY PERCENTAGE DISTRIBUTION OF ACCIDENTS AND CONFLICTS
LOCATION: TORONTO
CONFLICTS
ACCIDENTS
PERCENT OF TOTAL OCCURRING IN 1-HR. PERIODS
40
30
20
10
8
9
10
11
12
1
2
3
4
5
6
7
TIME OF DAY

FIGURE 18


COMPARISON BETWEEN WEEKDAY PERCENTAGE DISTRIBUTION OF ACCIDENTS AND CONFLICTS
LOCATION: ALL INTERSECTIONS
CONFLICTS
ACCIDENTS
40
30
20
10
PERCENT OF TOTAL OCCURRING IN 1-HR. PERIODS
8
9
10
11
12
1
2
3
4
5
6
7
TIME OF DAY

Employing the subscripts: a - Accidents
b - Conflicts
v - Volumes
i - Indices

we obtain the following table:

coefficient	value	Explanation
$r_{ac.v}$	0.111	Correlation between 2 & 1. having eliminated the effects of 3 on 1.
$r_{ai.v}$	0.249	
$r_{av.i}$	0.426	
$R_{a.cv}$	0.650	Combined correlation of 2 & 3 on 1.
$R_{a.ci}$	0.642	
$R_{a.vi}$	0.705	

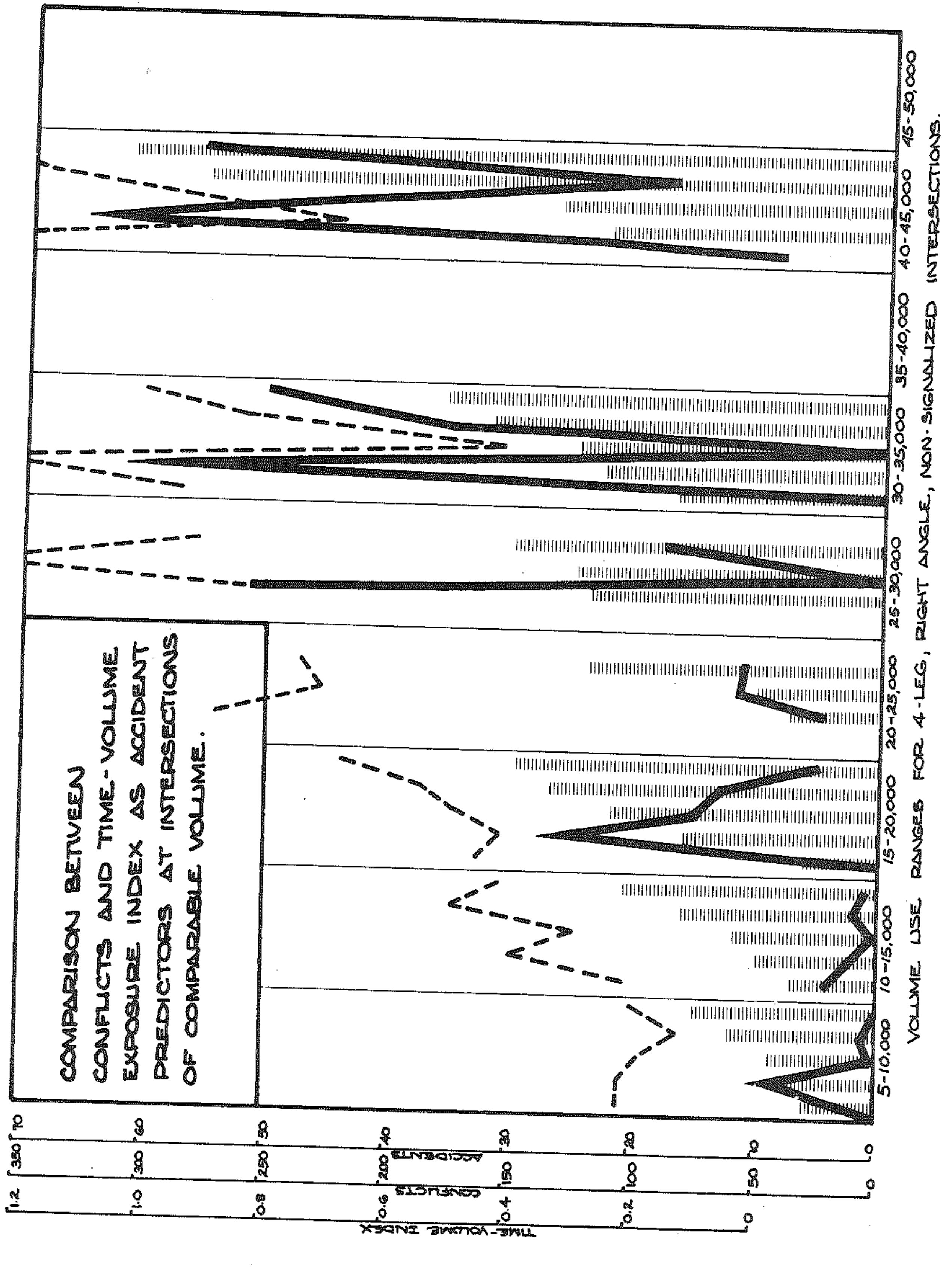
Squaring the above 'r' values indicates the fraction of total variance which the variable in question explains with respect to the accident relationship.

From this table it is obvious that conflicts alone are a rather poor predictor of accidents since they can explain independently only 1.2% of the variance. The time-volume exposure index is considerably better at 6.3% but this is still very low, the highest single correlating factor being simple volume totals at 18.1%.

When the variables are combined however, they are capable of explaining a much higher proportion of the variance with volumes and indices together accounting for about 50%. This suggests the usefulness of performing a multiple regression analysis involving all the significant variables employed in the study.

Two variables, conflicts and violations, as can be seen from Table 5 and the above analysis, are not likely to contribute significantly to the model and in fact, when one compares the multiple regression equations calculated both with and without these factors, they can be shown to account together for less than 1% of the accident sample variance.

FIGURE 19


COMPARISON BETWEEN CONFLICTS AND TIME-VOLUME EXPOSURE INDEX AS ACCIDENT PREDICTORS AT INTERSECTIONS OF COMPARABLE VOLUME.
VOLUME USE RANGES FOR 4-LEG, RIGHT ANGLE, NON-SIGNALIZED INTERSECTIONS.
5-10,000
10-15,000
15-20,000
20-25,000
25-30,000
30-35,000
35-40,000
40-45,000
45-50,000
ACCIDENTS
0
10
20
30
40
50
60
70
CONFLICTS
0
50
100
150
200
250
300
350
TIME-VOLUME INDEX
0
0.2
0.4
0.6
0.8
1.0
1.2

The best model is then represented by the equation:

$$A^* = 3.069 + 9.898E + 0.0004992v$$

which explains 53% of the sample variance

Figure 19 illustrates the separate effects of volume, time-volume exposure index and conflicts on accidents. While volumes and exposure index (dashed lines) appear reasonably consistent with accidents (bar graphs), at least for low and medium volume intersections, it is evident that conflicts (solid lines) are erratic. Taking Figure 19 in conjunction with Table 7 discussed previously, it would seem that a volume based predictor model is certainly superior to one developed from the concept of conflicts as applied in this study. The discussion of section 3.6.8 also confirms this conclusion.

The only areas where conflicts presented themselves as a useful statistical tool was in the analysis of possible hazard situations by time of day and by area placement within an intersection. This is not to suggest that the analysis of conflict situations by monitoring an intersection cannot perform a useful function. The simple procedure of detailed observation itself can provide additional insight into traffic problems and may well suggest valid solutions.

Nor is it intended to suggest that the concept of traffic conflicts has no potential as a statistical tool for predicting accidents. What the results of this study would seem to imply is that the current state of the concept and definition of traffic conflicts may be inadequate for providing a useful statistical model in the prediction of accidents.

It is evident that considerably more work is needed in modelling traffic accident occurrence. Using four variables which included all of the basic observational measurements taken at intersections, the best result which this study could provide was one which accounted for only slightly more than half of the accident sample variance, that is, almost half of the variance remained unaccounted for.

Some form of exposure index based on conflicting manoeuver volumes and times might provide the answer, as the ability of the index introduced in this study to account for some of the accident variations among similar volume locations has indicated, but its overall low efficiency in predicting the correct order among the accident locations themselves suggests that considerable reassessment is required.

3.6.9 Conflicts and Violations

Violations, and the resulting conflicts, are summarized in Table 11. The most hazardous violations, in terms of resulting conflicts, occurred when vehicles crossed over the roadway centerline when turning and when they made a turn from an improper lane thereby cutting-off through traffic. In these two cases conflicts resulted from 3.4 and 1.7% of the violations respectively.

All other violations recorded (turn into wrong lane, no turn or lane change signal and failing to make a legal stop at a stop sign) involved conflicts in less than 1% of the cases.

In order to determine the likelihood of a violation resulting in a hazardous (conflict) situation, conditional probabilities were calculated for conflicts arising from each violation type. In order to make the necessary comparisons some of the violation classes had to be redefined somewhat; for instance the category of weaving infractions contained all violations related to changing lanes and turning to and from the wrong lane, and this category was compared with weaving conflicts which were similarly defined.

Table 12 summarizes the steps and results involved.

The factor $P(C/V)$ represents the probability of a conflict occurring as a direct result of a violation while $P(C/\overline{V})$ is the probability of a conflict when no violation has taken place. If, therefore, $P(C/V)$ is greater than $P(C/\overline{V})$ it is possible to say that a certain violation has a tendency to result in conflicts in that this type of conflict is more likely to occur following the violation than as part of the ordinary course of events.

TABLE 11

TABLE OF VIOLATIONS AND CONFLICTS
RESULTING FROM VIOLATIONS

Turn from wrong lane		Turn to wrong lane		No lane change signal	
Violations	Conflicts	Violations	Conflicts	Violations	Conflicts
4,472	74	11,824	28	9,873	71
%	1.7	%	0.2	%	0.7

No turn signal		Through Stop Sign		Cross over center line.	
Violations	Conflicts	Violations	Conflicts	Violations	Conflicts
60,083	59	11,225	41	887	30
%	0.1	%	0.4	%	3.4

Accordingly the data indicates that weaving and cross-centerline infractions are relatively hazardous even though the chance of being involved in a conflict is only about 1.7 and 3.4% respectively. This is because weaving and cross-traffic conflicts are 2 to 9 times more likely to occur following a related violation than on the average.

On the other hand, in the case of failure to signal turns and failure to execute a proper stop when required, $P(C/V)$ is significantly less than $P(C/\overline{V})$. This is especially true for the signal infraction. What this indicates is that drivers, for the most part, commit such violations only when it is safe to do so, that is, when no conflicting traffic is present. If there is no traffic on a major route then a driver who proceeds directly through a stop sign does not incur any risk. Such violations could possibly come under the heading of "folk crimes" the commission of which is largely sanctioned by the driving public. It may be, in such instances, that strict adherence to the letter of the law is detrimental to the credibility of the legislative and enforcement systems.

TABLE 12

CONDITIONAL PROBABILITY MATRICES FOR VARIOUS CLASSES OF INFRACTIONS.

1. <u>Weaving Infractions</u>
   - Changing lanes without signalling, turning from or to the wrong lane (weaving conflicts)

	C	C
V	173	25,996
V	141	248,073

$$P(C/V) = \frac{VC}{VC + VC} = \frac{173}{173 + 25{,}996} = \underline{.00661}$$

$$P(C/V) = \frac{CV}{CV + CV} = \frac{141}{141 + 248{,}073} = \underline{.000568}$$

$$P(C) = \frac{VC + VC}{VC + VC + Vc + CV} = \frac{173 + 141}{173 + 141 + 25{,}996 + 248{,}073}$$

$$= \underline{.00114}$$

2. <u>Failure to Signal turns.</u>
   (slow-for-turn rear end and left-turn conflicts).

	C	C
V	59	60,024
V	2,173	178,874

$$P(C/V) = \frac{59}{59 + 60{,}024} = \underline{.000982}$$

$$P(C/V) = \frac{2{,}173}{2173 + 178{,}874} = \underline{.0120}$$

$$P(C) = \frac{59 + 2173}{59 + 2173 + 60{,}024 + 178{,}874}$$

$$= \underline{.00926}$$

Table 12 continued

3. <u>Through Stop Sign Infractions</u>

	C	C
V	41	11,184
V	2,203	131,600

$$P(C/V) = \frac{41}{41 + 11,184} = \underline{.00365}$$

$$P(C/V) = \frac{2203}{2203 + 131,600} = \underline{.0165}$$

$$P(C) = \frac{2203 + 41}{2203 + 41 + 11,184 + 131,600}$$

$$= \underline{.0155}$$

4. <u>Cross Centre Line Infractions</u>
- Mainly during turning manoeuvers (cross-traffic conflicts)

	C	C
V	30	857
V	2214	141,927

$$P(C/V) = \frac{30}{30 + 857} = \underline{.0338}$$

$$P(C/V) = \frac{2214}{2214 + 141,927} = \underline{.0154}$$

$$P(C) = \frac{30 + 2214}{30 + 2214 + 857 + 141,927}$$

$$= \underline{.0155}$$

4. Conclusions and Recommendations

1. The concept of traffic conflicts has much promise in theory but in general, the results of this study did not indicate a very efficient or practical application. A large part of the problem undoubtedly stems from the use of human observers in whom no amount of training can eliminate completely all traces of bias and variability. Strangely enough, however, it is the use of experienced human observers which probably lends the present conflicts technique what usefulness it may have. That is to say, by utilizing the detailed observational techniques employed in conflict counting, a remedial solution to hazardous location may become obvious through trained observance alone, regardless of the statistical results of the conflict count.

2. Conflicts were found to be extremely volume dependent and could not account for difference in accidents when corrected for volume exposure.

3. There is a conceptual problem in the definition of a conflict in terms of its severity. For instance, certain types of conflicts are likely to be more severe, on the average, than others (cross-traffic as opposed to rear end for example) and thus it may be invalid to give all conflict categories the same weight in developing a working model. The more liberal the definition of a conflict the easier it is to reproduce the count and record statistically significant amounts of data, but at the same time the efficiency of the statistic in predicting accidents is reduced. Near accidents have been shown, not unexpectedly, in the past to correlate well with accidents and this study has indicated that violations, on the other end of the spectrum, do not. A re-evaluation is needed of the definitions involved in order to arrive at a statistic which is both efficient and repeatable, and in this regard it may be necessary to consider some alternative to the current total reliance on human observation and judgement.

4. It appears that, using accident predictor models developed from the current state of the art, some form of volume exposure statistic is as efficient or better than conflicts in their present form when attempting to rank locations by gross numbers of accidents. There does seem to be an application for conflicts in identifying high accident areas within an intersection where simple volumes are insensitive to the locational distinctions required. Conflict counts also confirm the typical daily fluctuations in accidents at intersections

but since these also correspond to volume changes there is no evidence of independent correlation.

5. The use of time exposure in conjunction with cross-volume products produced a statistic generally superior to conflicts and which was, in some instances, able to explain differences in accident history among similar volume intersections. None of the statistics employed, including conflicts, however, were sufficiently reliable for the identification of specific, problem intersections or the accident producing mechanisms involved at individual locations.

6. The data collected concerning violations give rise to questions with respect to the enforcement of some traffic laws. While the data presented in this study is not sufficient for any definite conclusions in this regard, there was evidence to suggest that some regulations are deliberately violated only when the driver judges it safe to do so, and thus disregard of these laws may not prove statistically unsafe. This could have ramifications in terms of the credibility of enforcement procedures.

In summary, while both conflicts and volume exposure factors correlated significantly with accidents over the total sample of intersections, this correlation, especially for conflicts, was not of a high order, and even when combined in a multiple regression analysis, only managed to explain some 50% of the accident sample variance. This performance is simply not good enough for application as a useful engineering tool and it is evident that more research is needed with conflicts and other predictors in order to develop a suitable model relating driver behaviour to accident occurence. The fact that significant correlations were achieved, and have also been reported by other observers, however, would seem to indicate that the concept of traffic conflicts is at least a valid one and that further work in this area is justified.

5. REFERENCES

1. Anderson, J.W. and Nordholm, L.A., "Right Turn on Red Accident Study", Minnesota Department of Highways, No. 346, 1969.

2. Automotive Safety Foundation, "Traffic Control and Roadway Elements - Their Relationship to Highway Safety", Washington 1963 (and subsequent revisions).

3. Baker, W.T., "Evaluating the Traffic Conflicts Technique". Presented at the 51st Annual Meeting of the Highway Research Board, Washington, D.C., Jan., 1972.

4. Box, P.C., "Major Intersection Improvement - An Urban Example", Public Safety Systems, pp. 13-16, July 1968.

5. Breuning, S.M. and Bone, A.J., "Interchange Accident Exposure", HRB Bulletin No. 240, pp. 44-52, 1960.

6. Campbell, R.E. and King, L.E., "The Traffic Conflicts Technique Applied to Rural Intersections", Accident Analysis and Prevention, Vol. 2, pp. 209-221, 1970.

7. Chapman, R.A., "Traffic Collision Exposure", Proceedings of Road Symposium Session D, Road Research Unit, National Roads Board, Wellington, N.Z., 1967.

8. Charlesworth, G., Tanner, J.G., "Road Junctions in Rural Areas", Road Research Technical Paper No. 47, Road Research Laboratory, London, 1960.

9. Colgate, M.G., Tanner, J.C., "Accidents at Rural Three-Way Junctions", RRL Report LR 87, Road Research Laboratory, London, 1967.

10. Davidson, Bruce M., "Vehicular Paths in Certain Types of Intersection Areas", HRB Proceedings, Vol. 36, pp. 575-576, 1957.

11. Faulkner, C.R., "Research on Accidents at Road Junctions", Journal of the Institution of Highway Engineers, Vol. XVI, No. 12, December 1969.

12. Forbes, T.W., "Analysis of Near Accident Reports", Highway Research Board, Bulletin 152, Washington, D.C., 1957.

13. Forwood, A.V. and Pretty, R.I., "A Comparison of Right of Way Rules at Intersections", Proceedings of 4th

Conference of Australian Road Research Board, Vol. 4, Part I, pp. 616-632, 1968.

14. Groeben, N. and Sader, M., "Impressions of Traffic Density and Accident Frequency", Zeitschrift Verkehrssicherert, Vol. 14, No. 1, pp. 35-48.

15. Hammer, Charles G., Jr., "Evaluation of Minor Improvements", HRB Record No. 286, pp. 33-45, 1969.

16. Hayward, J.C., "Near Miss Determination Through Use of a Scale of Danger", Highway Research Record No. 384, pp. 24-34, Washington, D.C., 1972.

17. Heany, John J., "4-Way Stop - A Highly Effective Safety Device", City of Philadelphia Traffic Dept., 1970.

18. Heany, John J., "How to Identify Dangerous Intersections", City of Philadelphia Traffic Dept., 1969.

19. Highway Users Federation, "Report on Intersection Accidents", Washington, D.C., 1970.

20. Hoffman, M.R., Lampela, A.A. and Scarcella, F.R., "Evaluation of a Safety Project - Widening of M-17 from Four to Five Lanes to provide a Center Lane for Left Turns", Michigan Department of State Highways, Dec. 1968.

21. Hoffman, M.R., Lampela, A.A. and Alashari, N., "Evaluation of a Removal of Curb Parking and Conversion to Five Lane Street Operation", Michigan Dept. of State Highways, Nov. 1968.

22. Hoffman, M.R., Lampela, A.A. and Alashari, N., "Evaluation of a Safety Project - Replacement of Bi-Directional Crossover with Pair of Directional Crossovers", Michigan Dept. of State Highways, June 1969.

23. McDonald J.W., "Relation Between Number of Accidents and Traffic Volume at Divided-Highway Intersections", HRB Bull. No. 74, U.S.A. 1953.

24. McMonagle, J. Carl, "Relation of Traffic Signals to Intersection Accidents", HRB Bulletin No. 74, 1953.

25. Michigan Dept of State Highways, "A Study of Selection of Yellow Clearance Intervals for Traffic Signals", Traffic and Safety Division, Lansing, Michigan, 1969.

26. Minnesota Highway Dept., "Right Turn on Red Accident Study", Traffic and Surveillance Section, Office of Traffic Engineering, 1969.

27. National Cooperative Highway Research Program, Report 11, "Effect of Control Devices on Traffic Operations - Interim Report", Highway Research Board, Washington, 1964.

28. Newby, R.F., "Accident Frequency at Signal-Controlled Crossroads with an All-Red Period", Traffic Eng. and Control No. 2, 1961.

29. New Jersey Dept. of Transportation, "Intersection Design", Bureau of Safety and Traffic, 1969.

30. Ohio Dept. of Highways, "The Effect of Flashing Traffic Control Devices on Accident Occurrence", Bureau of Traffic, 1967.

31. Older, S.J., "Accident Comparisons at Halt or Stop Junctions", Traffic Eng. and Control No. 11, 1961.

32. Perkins, S.R., and Harris, J.I., "Traffic Conflict Characteristics - Accident Potential at Intersections", Highway Research Record No. 225, Highway Research Board, Washington, 1968.

33. Roer, P.O., "Traffic Safety and the Use of Intersection Control Devices", Canadian Good Roads Association, Proceedings of the 1968 Convention.

34. Roer, P. and McLaughlin, W.A., "Safety Aspects of Intersection Control Devices", Waterloo University.

35. Schoene, G.W. and Michael H.I., "Effects of a Change in the Control Device on Intersection Accidents", Proceedings of the 52nd Annual Road School, Purdue University, Extension Series No. 123, Vol. 50, No. 4, pp. 138-155, July 1966.

36. Sinha, Kumares C. and Tomiak, Walter W., "Section Gap Acceptance Phenomenon at Stop-Controlled Intersections", Traffic Engineering, April 1971.

37. Solberg, P. and Oppenlander, J.C., "Lag and Gap Acceptances at Controlled Intersections", H.R.B. Record, No. 118, 1966, p. 48-67.

38. Solomon, D., "Traffic Signals and Accidents in Michigan", Public Roads No. 10, 1959.

39. Spicer, B.R., "A Pilot Study of Traffic Conflicts at a Rural Dual Carriageway Intersection", Road Research Laboratory Dept. No. LR410, Dept. of the Environment, Crowthorne, England, 1971.

40. Spurr, R.T., "Subjective Assessment of Brake Performance", Automobile Engineer, Vol. 55, No. 9, Sept. 1965.

41. Stillman, I.L., "Traffic Flow Sensing and Surveillance System", Cornell Aeronautical Laboratory, Report No. CPR-11-00956, 1968.

42. Surti, Vasant H., "Accident Exposure and Intersection Safety for At-Grade, Unsignalized Intersections", HRB Record No. 286.

43. Systems Research and Development Institute of Japan, "Preventive Measures Against Traffic Accidents in the Intersection", Toyko, June 1971.

44. Thomas, R.C., "Continuous Left Turn Channelization and Accidents", Traffic Engineering, Inst. of Traffic Engineers, Vol. 37, No. 3, pp. 37-40, Dec. 1966.

45. Wagner, F.A., "An Evaluation of Fundamental Driver Decisions and Reactions at an Intersection", Highway Research Record 118, 1966, pp. 68-84.

46. Webb, G.M., "The Relation Between Accidents and Traffic Volumes at Signalized Intersections", Inst. of Traffic Eng. Proceedings 1955.

<u>Other Relevant Publications and Studies not Directly Referenced in this Report</u>

1. Andreassend, D.C., "Another Look at Traffic Signals and Accidents", Proceedings, 5th Conference of the Australian Road Research Board, Vol. 5, Pt. 3, 1970.

2. Baldock, R.H., "Left Turn Accidents: A Study of Accident Frequencies Occasioned by Left Turns on Four-Lane Divided Highways", Traffic Engineering, 1946.

3. Bennett, G.T. "Road Junctions: Suggestions for Improved Designs", Public Works, Roads and Transport Congress and Exhibition, Final Report, London, 1947.

4. Berry, D.S., Kell, J.H., "Use of Yield Signs", Traffic Engineering, Vol. 26, No. 4, Jan. 1956.

5. Creech, M.F., "Traffic Signals: Their Effect on Accidents", Thesis for the Bureau of Highway Traffic, Yale University, 1968.

6. Detroit Dept. of Traffic Control, "One Year and After Study at a Yield Sign Location", 1958.

7. Dobelek, J.J., "Intersectional Islands and Traffic Accidents", Traffic Engineering, Vol. 21, No. 5, Feb. 1951.

8. Garwood, F., Tanner, J.C., "Accident Studies Before and After Road Changes, Final Report, Public Works and Municipal Services Congress, 1956.

9. Inwood, J., Newby, R.F., "Yield Signs", Surveyor, London, 1959.

10. Monseur, M., "Driver's Decision Making at Road Intersections", International Symposium on the Man-Machine System, Institute of Electrical and Electronics Engineers and Ergonomics Research Society, Sept. 1969.

11. "Research into Road Safety at Junctions in Urban Areas", Organization for Economic Co-operation and Development, Paris, 1971.

12. Quenault, S.W., "Development of the Method of Systematic Observation of Driver Behaviour", Road Research Laboratory Rept. LR 213, Crowthorne, England, 1968.

13. Raff, M.S., "Interstate Highway Accident Study", Highway Research Board Bulletin No. 47, Washington, 1953.

14. Ray, J.C., "Experience with Right Turn on Red", Traffic Engineering, No. 3, 1957.

15. Roer, P.O., "Pedestrian Crossovers", Traffic Engineering No. 11, 1961.

16. Rotman, M., "The Toronto Pedestrian Crossover Program", Traffic Engineering, No. 5, 1961.

17. Staffelt, P.R., "Accidents Related to Access Points and Advertising Signs in Study", Traffic Quarterly, No. 1, 1953.

18. Summerfield, K., "Design of Road Intersections", Proceedings of the Institute of Civil Engineering, Part II, 1956.

19. Syrek, D., "Accident Rates in Intersections", Traffic Engineering, No. 8, 1955.

20. Tanner, J.C., "Accidents at Rural Three-Way Junctions", Journal of the Institute of Highway Engineers, Vol. 2, No. 11, 1953.

21. Tanner, J.C., "Accident Frequencies Before and After Layout Changes at Junctions", Road Research Laboratory Research Note RN/3494/JCT, Crowthorne, England.

22. Thorson, O., "Traffic Accidents and Road Layout", Technical University of Denmark, 1967.

APPENDIX

DEVELOPMENT AND CALCULATICN OF THE TIME-VOLUME

EXPOSURE INDEX

Based on the findings of Charlesworth and Tanner (8) and McDonald (23) a possible relationship between accidents and intersection approach volumes is of the following form:

$$A \propto \sqrt{Q_1 Q_2}$$

where Q_1 and Q_2 are the intersecting approach volumes.

Using the approach volumes, however, provides a gross index which is insensitive to the traffic demand weights assigned various different movements.

If volume counts for each separate vehicular movement are obtained then the root of the intersecting volumes for each can be calculated as above, and the total index for the intersection will be the summation over all allowable movements.

This provides a measure of vehicle placement or frequency of a particular manoeuver which exposes a vehicle to possible collision. It says nothing, however, about the probability that, once exposed, the vehicle will be struck by an opposing one.

The actual probability, since it depends on human and environmental factors to such a large extent, is impossible to calculate, however it can at least partially be represented by the time which the vehicle is exposed to opposing traffic.

Thus the likelihood of accident occurrence should vary as the product of the time and volume exposure. This product results in a dimensionless variable which can be termed an "exposure index".

Once again, summing these indices over the entire range of vehicular movements or possible conflicting traffic streams results in an overall exposure index for the intersection. A factor of 2.78×10^{-4} is required to balance the time factors if exposure time, t, is in seconds and volume Q is in vehicles per hour.

Then the exposure index can be expressed by:

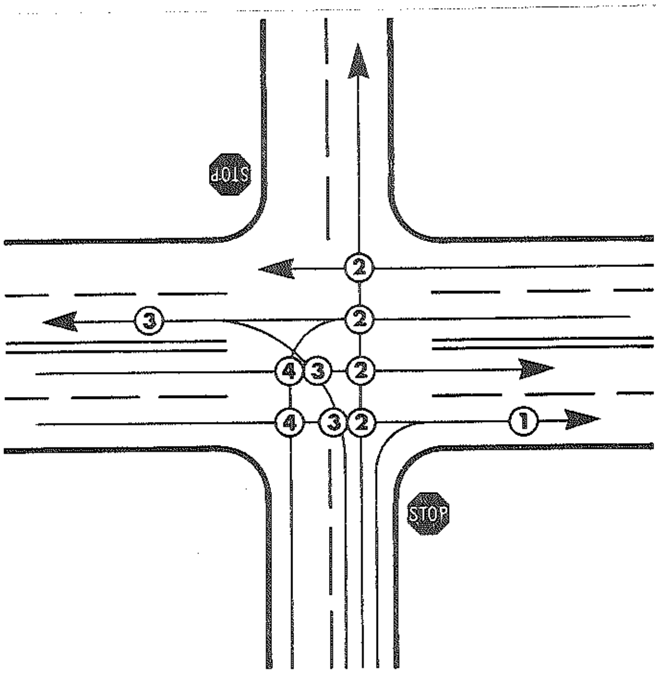
$$E = 2.78 \times 10^{-4} \sum_i t_i \sqrt{Q_1 Q_2}$$

where Q_1 and Q_2 are the intersecting or conflicting volumes involved in each vehicular movement, i, for which an average time of ti seconds is required.

Exposure times were taken by stopwatch at all intersections under study and the average for each manoeuver was computed from a minimum of 12 observations with the highest and lowest rejected. At the same time, traffic volumes were recorded for a total of 14 hours.

On the following pages are the detailed methods for calculating exposure indices for the two types of intersections studied:

(a) 4-leg Intersection



For this configuration there are 10 basic conflict points between traffic streams. In calculating the time-volume exposure index, however, only 8 are employed. This is because, at the intersection of a major road with one controlled by a stop sign, a left turn conflicting movement involving twc minor road vehicles is associated with a lower risk factor due to the fact that both vehicles start the manoeuver from a stationary pcsition and the resulting low speeds greatly enhance the probability of accident avoidance. This intuitive hypothesis is confirmed by an analysis of the data on left turn accidents which shcws that over 90% involve vehicles turning from the majcr route across moving traffic lanes. Support for this ccnclusion has already been mentioned with regard to the work of Charlesworth and Tanner (8).

It was recognized that cmission of the two minor road left-turn conflict manoeuvers would result in a few cases where left-turn accidents would not be predicted by the index, but it was felt that the general overemphasis on left-turn accidents resulting frcm the inclusion of these movements would overshadow the marginal benefits which could be obtained in a few of the cases.

Accordingly the analysis of a four-leg intersection proceeded as follows:

$$E = 2.78 \times 10^{-4} \left[t_1 (Q_1 \times q_1)^{1/2} + t_2 (Q_2 \times q_2)^{1/2} + t_3 (Q_3 \times q_3)^{1/2} + \ldots + t_8 (Q_8 \times q_8)^{1/2} \right]$$

where q_1 & q_2 = volume/hr of left turn vehicles on major route in each direction.

Q_1 & Q_2 = volume/hr of through vehicles on major route in each direction.

q_3 & q_4 = volume/hr of through vehicles on minor route in each direction.

Q_3 & Q_4 = volume/hr of all through vehicles on major route ($Q_3 = Q_4$)

q_5 & q_6 = volume/hr of left turn vehicles on minor route in each direction.

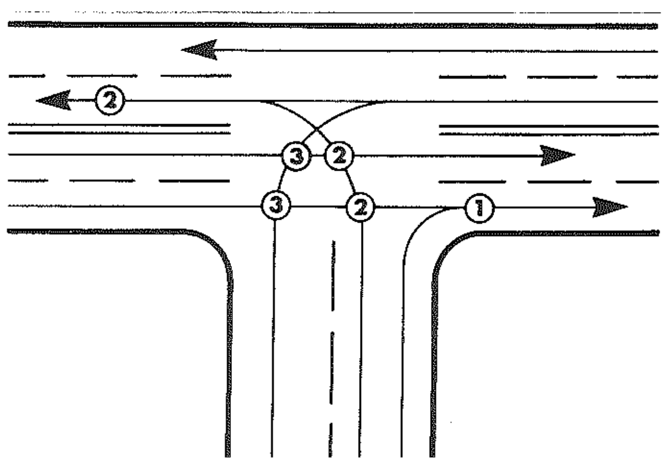
Q_5 & Q_6 = volume/hr of through vehicles on major route in each direction but only for lanes crossed normally or merged with.

q_7 & q_8 = volume/hr of right turn vehicles on minor route in each direction.

Q_7 & Q_8 = volume/hr of through vehicles on major route in right-hand lane in each direction.

The above equation will require fewer terms in cases where one or both of the roads is designated as one-way.

(b) "Tee" Intersection



In the case of a three-leg or "tee" intersection only 3 conflicting manoeuvers are possible. The equation will therefore contain only three terms, that is:

$$E = 2.78 \times 10^{-4} \left[t_1 (Q_1 \times q_1)^{1/2} + t_5 (Q_5 \times q_5)^{1/2} + t_7 (Q_7 \times q_7)^{1/2} \right]$$

where the symbols q_1, q_5, q_7, Q_1, Q_5 and Q_7 have been defined in (a) above.

While the index, in its above form, cannot theoretically account for rear end and weave accidents due to the lack of a measureable exposure time for these situations, a rough model can be postulated. For instance, regardless of the distance required for a car to stop, it could be assumed that all cars in a moving traffic stream have roughly the same braking capability and thus a rear end accident will only occur if the reaction time of the following driver is too long. The factor, t, in this instance then becomes the critical driver reaction time which depends on vehicle speed and physiological factors and which, if exceeded, with lead to an accident.

Since any vehicle in a continuous flow of traffic is exposed to a rear end or weave-type conflict from any other vehicle moving in the same direction we have the term:

$$t\ (Q \times Q)^{1/2} = tQ$$

Using t = 1 second, for example, the time-volume exposure indices can be re-calculated to include a specific term for rear end and weave accidents. In the case the overall accident correlation is slightly improved to 0.673. This would explain an additional 6% of variance over the old model, but still is no better than volume summation alone.