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Evaluating Pedestrian Safety Using
Traffic Conflict Technique

Massoud Javid

A Thesis

in

The Department

of

Civil Engineering

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for the Degree of Master of Engineering at
Concordia University
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ABSTRACT

Evaluating Pedestrian Safety Using
Traffic Conflict Technique

Massoud Javid

Traffic Conflict Technique (TCT) is used to evaluate pedestrian safety at urban intersections. The expected pedestrian conflicts are estimated on the basis of traffic activities such as pedestrian and vehicular flows and etc. A methodology is proposed for estimating vehicular and pedestrian flow from sample data.

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I would like to dedicate this thesis to my mother who provided me with the moral support and strength right throughout my years at school.

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LIST OF SYMBOLS

A = the expected number of a certain group of accidents during specified time.

ACT = Average clearance time (sec).

C = Total conflict at intersection (per hr)

CT = Clearance time (seconds).

E = exposure or opportunities of the same group of accidents during the same time period.

FPED_{max} = Maximum Five-minute Pedestrian Flow.

GRT = Vehicle green time (seconds).

$\lambda(t)$ = Mean pedestrian conflicts over time t .

LC = Conflicts occurring between the pedestrians and left turning vehicles at the intersections.

m'' = posterior mean.

m' = population mean taken over all similar sites

m_i = mean flow from a small sample at any site i

n = sample size used to calculate m_i

P = Hourly Pedestrians Volume.

$P(a)$ = probability of an accident resulting from one opportunity (propensity).

I_i = Proportion of all accidents involving pedestrian in sub-group i .

P_{ed} = Number of Pedestrians.

PE_i = Proportion of all exposures (or population) accounted for by sub-group i .

P_{GT} = Pedestrian green time (seconds).

P_L = Pedestrian volume crossing left turning vehicles.

P_R = Pedestrian volume crossing right turning vehicles.

Q = Total approach volume at intersection (per hr).

Q_L = Volume of left turning vehicles.

Q_O = Volume of opposing vehicles.

$Q_{PED_{max}}$ = Maximum 15-minute Pedestrian Flow.

Q_R = Volume of right turning vehicles.

$Q_{VEH_{max}}$ = Maximum 15-minute Vehicle Volume.

R^2 = Coefficient of determination

RC = Conflicts occurring between the pedestrians and right turning vehicles at the intersections.

RRR = relative risk ratio

S = Conflicts occurring between the pedestrians and
vehicles traveling straight through the intersections.

s" = Posterior standard deviation

s' = Prior standard deviation

TOTALPED = Peak-hour Pedestrian Volume.

TOTALVEH = Peak-hour Vehicle Volume.

Veh = Number of Vehicles.

WAT = Average walking time (seconds).

CHAPTER 1

INTRODUCTION

1.0 BACKGROUND

For over two decades traffic safety or rather unsafety has been a major concern of transportation agencies. During this period different measures have been used to classify and quantify transportation systems elements according to safety. These measures have also been of use to evaluate changes due to employment of countermeasures.

The most common measures are accident rates, such as accidents per population. However, the data related to the circumstances which have led to an accident, such as, speed, volume, the environmental and driving conditions, are often unknown or uncertain. Several researchers have proposed other measures.

Exposure and traffic conflicts are two of the measures widely used in transportation safety analysis. Even though, the two are similar in many ways, each one is used under different circumstances as discussed below.

1.1 EXPOSURE

The concept of exposure is used in a wide range of safety studies to interpret accident data and to estimate expected accident rates. Exposure is also used to evaluate the effectiveness of the accident countermeasures.

There are, however, many different definitions of exposure and the concept of exposure. Chapman (1973), for example, defines the opportunities of accidents of a certain type to occur in a traffic system during a given time period of time. On this basis, the expected number of accidents is expressed as;

$$A = P(a) * E$$

where;

A = the expected number of a certain group of accidents during specified time;

E = exposure or opportunities of the same group of accidents during the same time period; and

P(a) = probability of an accident resulting from one opportunity (propensity).

For exposure at intersections, Hodge and Richardson (1984-I) use the term propensity defined as an inverse function of the product of conflicting volumes. The same two

authors have reviewed other models that consider the probability or "potential" of accidents for defining site exposure -number of opportunities for accidents occurring at a given site(s)- of hazardous transportation situations.

Siddiquee (1973) and May (1971) have derived models to predict the number of potential conflicts at air route intersections. These two models use an approach similar to the one used by Hodge and Richardson (1984-I), where the product of the conflicting flows are used to describe exposure.

Carroll et al. (1971) define exposure as " the frequency of traffic events that create the risk of accidents.". Rochon et al. (1978) utilize a similar definition of exposure. They assume that two basic factors contribute the risk of an accident; (1) The amount of driving, and (2) the conditions under which driving is taking place. The explanation behind the first factor is that the more the vehicles are driven, the more they are exposed to accident risk. This can be easily measured in terms of the vehicle-miles or any other reasonable quantities. The second factor is defined in terms of the roadway conditions (e.g. lighting and weather conditions, time of day, etc.), which are difficult to measure. Thus, traffic characteristics such as speed and traffic volume could be incorporated to represent the risk of driving.

Wass (1982) defines exposure as a measure of the number of events that may result in an accident. This measure is defined in terms of factors such as mileage, traffic environment, and etc. Wass (1982) presents a mathematical model for deriving estimates of road-user exposure and liability from accident frequency statistic. The model relates the occurrence of accidents to accident opportunities (exposure) and personal situation factors (liability). Liability is defined as time-dependent personality factors such as fatigue, aggression, and impaired vision. They assume that the isolation of the liability component of an accident allows an estimate of exposure which is more cost effective and faster than the one obtained from the survey methods. For this purpose, different road-user groups were identified by age, sex, traffic modes, lighting conditions and severity. The data are then considered for two groups of the road users, female and male. No distinction is made between drivers, pedestrian, public transit users, etc.

Jonah and Engel (1983) conducted a study to develop a measure of the relative risk of the pedestrian accidents. The objective was to identify target groups by comparing their risk levels. They examined the relationship between accidents and frequency of crossing, walking distances, and time spent on the streets. They also defined a ratio as relative risk ratio (RRR).

$$RRR = PA_i/PE_i$$

where;

PA_i = Proportion of all accidents involving pedestrians
in subgroup i ;

PE_i = Proportion of all exposures (or population)
accounted for by subgroup i .

Jonah and Engel (1983) adopted the approach recommended by Thorburn and Wolfe (1979), who had suggested that duration of an activity (trip) is the most direct measure of exposure to an accident, because " it is applicable to all pedestrian activities; it is comparable to other transportation modes; it can be easily broken down in terms of other factors such as time of the day etc."

The reason for using duration of the trips as the measure of exposure, was the belief that longer a road user (pedestrian) uses (walks) the network, there are more chances of her or she crossing a greater number of paths (streets), resulting in higher exposure. Even though, the previous statement may be true, the time duration assumes that all the crossings have equal accident risk and the same increase in duration of all the trips equally increases the number of streets crossed for these trips.

Jonah and Engel (1983) in their study interviewed pedestrians by telephone and used police accident files in order to find the relationship presented in their research. The telephone survey was used as a tool to identify the factors contributing to pedestrian exposure. The questions asked in the survey focused towards clarifying the following factors; (1) purpose of trip, (2) start time, (3) distance, (4) number of streets crossed, (5) location of crossing, (6) light and weather conditions, and (7) accompaniment by others.

Using the information collected, Jonah and Engel suggest four indices of pedestrian exposure ; (1) the average number of trips, (2) the average distance traveled, (3) the average duration of trips; and (4) the average number of streets crossed.

The exposure data obtained by telephone did not consider the following factors which have an effect on pedestrian accidents (especially accidents at intersections).

1. Pedestrian flow.
2. Time for pedestrian to cross the intersection or street.
3. Geometry of the intersection or street.
4. Traffic flow.
5. Traffic control configuration (stop-sign, signalized).
6. Right of way.

7. Vehicle speed.

Also, the accuracy of the responses in telephone interviews can sometimes be questionable.

Toomath and White (1982) used distance traveled as a measure of exposure in their study of driver exposure. They found that this measure had a large sampling error for estimated distance traveled in past two years (road-side interview), however, the response to activities over shorter periods of time showed better results.

Cameron (1982) defines the pedestrian accident exposure as a product of number of " pedestrian (P) and vehicles (V) arriving at the road section during a time interval in which the arrival rates are constant ". It is reported that this relationship holds true unconditionally (for the pedestrian flows observed in Australia) for the road sections with pedestrian priority, as well as for the road sections with vehicle priority when the vehicle flow is light to medium.

Pedestrian accident exposure (PV), is described with two features;

1. Number of intersecting pedestrian and vehicle paths in a specific time interval; and

2. P and V are broken down in a way that $P = \sum P_i$ and, $V = \sum V_j$, where i and j are respectively the pedestrian-specific and vehicle-specific descriptors.

Cameron (1969) states that land use on each side of a road section significantly effects the pedestrian and vehicle arrival rates. Robertson (1983) uses the same concept of pedestrian and traffic volumes except that he includes the turning volume in the exposure variable (PV).

Bruhning and Volker (1982) report different measures of exposure for different studies. For example:

(a). Exposure for large study areas, groups or times;

When using a large aggregated accident data set (to obtain the risk of accident), the reference values (exposure) such as, total vehicle mileage of a city, province, or country can be used for comparison. Other measures suggested for such cases are population, length of the road network, duration of the road usage with respect to vehicles or persons etc. The risk level obtained from this exposure measure can be useful in cases evaluating the safety of a large area such as a province or country, and the effectiveness of traffic safety countermeasure(s) such as lowering the speed

limit, increasing the age of driving, etc., that is(are) employed over a large area.

(b). Exposure for specific locations or persons;

A general exposure measure, as mentioned previously, is of little use when studying the accidents of certain types of road user (e.g. female or male drivers , pedestrians) or certain sections of a road network (e.g. intersections, rural or urban roads, pedestrian crossings). In the case of road users, values such as the amount or length of road usage by each group have been used as measures of exposure. For specific locations measures such as the number of pedestrians, passing vehicles, or traffic volumes can also be used.

(c). Conflict-oriented exposure measures;

The number of events that may result in an accident can be used as a measure of exposure. Events such as a road user crossing another user's path or a vehicle negotiating a curve may result in accidents.

Mahalel et al. (1982), in a study of black spots have discussed the following measures of exposure for the road sections and intersections. Traffic flows are studied as an estimation of exposure for the road sections. For intersections, (after studying variables such as; index of traffic flow, number of accidents in the previous period,

length of time the intersection was signalized, number of conflict points and the town that intersection is located in), they found that the summation of the product of traffic flows at the conflicting points of the intersection was a better measure of exposure at signalized as well as non-signalized intersections.

Using variables such as the length of time that the intersection was signalized should not make a difference in the exposure measure. Intersection is either treated as signalized or non-signalized. However, accident rates of an intersection can be different in the periods of before and after signalization (seems to be more related to evaluation of countermeasures). Similarly, the variable related to the town in which the intersection is located, seems to be a difficult variable to explain and quantify.

From the same school of thought, Ceder and Livenh (1982) investigated the relationship between traffic flows and accident rates of different types of road intersections and accidents. The models for multi-vehicle accident yield that most of the time (75%) the accident rate does not increase as sharply as traffic flow for upper and lower bound values of the traffic flow. The combined multi- and single-vehicle models present a U-shaped function for accident rate, however, the majority of curves (75%) representing the single-vehicle model of upper bound traffic flow are not

U-shaped.

Other studies, on this matter, have shown similar results, for example, Leutzbach (1966) and Gwynn (1967) concluded that between the accident rates (for the total accident) and traffic flow, there exists a U-shaped relation (for four-lane divided road sections). Brilon (1976) finds the same relationship between the accident rates and traffic flows. He also proposes a hypothesis that the minimum accident rate occurs during the most frequent traffic flows.

Risk and Shaoul (1982) summarize the previous works on exposure and suggest another method and concept for exposure different from the previously mentioned methods which aim primarily at interpreting accident data. This concept uses "exposure behaviour" as its main objective. They report that there are differences (sometimes contradictory) in miles traveled, (exposure) of trained and untrained child cyclists of different ages, and in the number of purposeful trips (percentage of exposure) they made. It was also found that there were differences between the mileage traveled (exposure) during the day time of trained and untrained drivers. Risk and Shaoul (1982) do mention that there is a need for more studies to examine the reliability and causes of their findings.

Risk and Shaoul (1982) state that "it is not possible to calculate a true accident probability using conventional mileage-exposure data, since no means exist by which the accident trials may be identified or counted. Accident rates, for this reason alone, cannot be taken as a true probability". Risk and Shaoul also state that increased exposure resulting from higher accident events, does not imply an increased probability that an accident will result from a given opportunity. It only suggest a higher number of trials.

Risk and Shaoul (1982) indicate the importance of distinguishing "exposure to risk" from "risk of exposure". It was proposed that "conflict" related measures should be used to predict accidents, since, they are more logically representative of accidents. They correlated the number of flow path intersecting points -potential "Conflict points"- with frequencies of observed hazards and accidents that happened at the same location over 45 months. They reported that the predictor variables (roads joining, possible manoeuvres and flow path conflict points) correlated almost to the same degree with accidents and hazards. The following is the list of variables (Flow Path Conflict Points) used by Risk and Shaoul (1982);

1. No. Potential Veh/Veh conflict points per zone.

2. No. Potential Veh/Veh conflict points (test route) points per zone.
3. No. Potential Ped/Veh conflict points per zone.
4. No. Potential Ped/Veh conflict points (test route) points per zone.
5. Total Potential Veh/Veh + Ped/Veh conflict points per zone.
6. Total Potential Veh/Veh + Ped/Veh conflict points (test route) per zone.

Hodge and Richardson (1984-II) also indicate that the distance based exposure measures (e.g. vehicle-mileage etc.) do not guarantee an accurate presentation of exposure in terms of "collision opportunities".

Hauer (1982) draws attention to differences in exposure measures. He suggests the use of "conflicts" and "near misses" to evaluate system safety. The explanation he offers is that the conflict occurrences are statistically reliable estimates that can be collected in a relatively short period of time and, a road network with many conflicts and near misses will probably have many accidents. Hauer in the discussion of the concepts of "conflict" and "exposure", states that the "traffic conflict" is a tool for indirectly estimating a system's safety. Hauer also states that "A unit

of exposure corresponds to a trial (opportunity of accident)". This trial could result in either "occurrence", or "non-occurrence" of an accident event, furthermore, risk is the probability of the occurrence of the accident from a trial. Hauer (1982) suggests that there is a need to clarify the definition of these two concepts.

1.2 CONFLICTS

As mentioned in some literature, there has been disagreement and uncertainty in the definitions of the "exposure" and exposure risk, which is essentially the potential "conflicts", [Hauer (1982)]. In general, a traffic conflict is an event involving two or more road users, where one or more users have to take an evasive action, in order to avoid collision. According to Glauz and Migletz (1980), traffic accidents are the conflicts which evasive action was taken too little or too late. Allen and Shin (1977) suggest that the definition of traffic conflicts has to imply that every accident is the result of a conflict. Another school of thought considers traffic conflicts as the events whose occurrence is directly comparable to the traffic accidents. However, this relation is yet to be proven, as discussed by Glennon et al. (1977).

Another definition was suggested at the First Workshop on Traffic Conflicts, see Van Den Hondel and Paary (1986), :

A traffic conflict is an observable situation in which two or more road users approach each other in space and time to such extent that there is a risk of collision if the movements remain unchanged". Hyden (1977) has used " time-to-collision " as a measure of conflict potential. It is defined as: the time from when a conflicting vehicle takes evasive action (brakes or swerves) until an accident or near miss would have taken place, if evasive action had not been taken. Hyden (1977) assumed that a conflict is severe when time-to-collision is 1.5 seconds or less.

Glauz and Migletz (1980) have modified the previous definition to fit the purpose of their research. They define a traffic conflict as a traffic event involving two or more road users, in which one road user performs some typical or unusual action such as change in direction or speed, which places another user in jeopardy of a collision unless an evasive maneuver is undertaken. Glauz and Migletz (1980) also present some useful operational definitions.

1.3 STUDY OBJECTIVE

Safety of pedestrians in central business districts (CBD) is a problem faced by planners and engineers of most large cities. For example, Seneviratne and Shuster(1988) reported that almost half the accidents that occurred in the Montreal's CBD during 1987 involved pedestrians. In order to

solve pedestrian safety problems, one needs a clear understanding of the types of pedestrian accidents as well as detailed information on the vehicles, environment and pedestrian behavior. Even with this information, it is not an easy task to either determine the cause of accidents, or to predict the frequency of accidents at a given site or area during a specific time interval.

Police accident reports are one of the primary sources of information available to researchers, but, often the accident report forms are not filled out at the time of accidents and/or records are incomplete. Certain aspects which could be useful in determining the causes of accidents are not even included in the forms. In other words, accident report forms are designed to retrieve information to aid legal proceedings than to retrieve and record information needed to develop engineering solutions.

The first step in the accident problem solving process is to identify the sites or areas which contain hazardous elements. For this purpose, several researchers and engineers have developed statistical models for estimating the expected number of accidents which in turn are used to establish the hazardous sites, Hagle & Witzowick (1988).

Another school of researchers have explored relationships between different measures of risk and basic

traffic parameters for classifying sites. The latter approaches tend to lend themselves to address situations where data are lacking or unreliable.

The objective of this study was to investigate the potential for using one of the latter approaches in order to identify hazardous intersections from the point of view of pedestrian safety. The Traffic Conflict Technique (TCT), which has been tested extensively as a tool for estimating risk was chosen for detailed analysis. This technique enables one to estimate the expected risk, in terms of pedestrian conflicts which can be explored via easily observable parameters such as, traffic flow, pedestrian flow and travel speed.

In addition to being quantifiable, these parameters can be expanded with reasonable accuracy if long term consequences are needed to be verified. Thus, as a part of this research, the variability of traffic and pedestrian flows, distribution functions, and the relationships between short-term and long-term flows were also examined. A method based on Bayesian theory is proposed for minimizing the sampling errors as well as updating flows.

CHAPTER 2

DATA COLLECTION

2.1 INTRODUCTION

Reliable and relevant data are one of the most important, if not the most important, item for planning, designing and managing traffic safety. If the appropriate tools are used to analyze and interpret this data, it would provide engineers or planners with an adequate understanding of the problems and possibly find solutions for problems of traffic safety.

Statistical theories and models can be of great value in many areas of transportation (traffic) engineering. These models in turn dictate the data requirements, including the size of the sample to be collected and the period of data collection, as well as the data collection techniques.

2.2 DATA COLLECTION

The data for this study were collected with the objective of understanding the inherent and periodic variations in vehicular and pedestrian flows, and conflicts between the vehicles and pedestrians. They were collected

during the mid-day peak (12:00-13:00 hrs.), in the summer of 1989, at nine intersections in Montreal's Central Business District and one intersection at another business district (north of downtown Montreal). Similarity of adjacent land-use, and highly peaked flow of pedestrian and vehicular traffic during the survey period were the two main deciding factors in selecting these sites.

In order to have these peaked flows, intersections in the vicinity of office buildings were chosen. Table 2.1 shows the surveyed intersections. The time period of 12:00 h to 13:00 h on week-days (Monday to Friday, holidays excluded) was chosen because it is the highest of the three daily peaks according to the data collected in other cities, [Seneviratne (1983)].

The data were collected by using video cameras and in some instances, observation were made manually to verify the data extracted from video tape. The video camera provided an opportunity to double check, discuss and clarify doubts especially in the areas of pedestrian conflict and pedestrian behavior during crossings. The only drawbacks in using the video camera were the difficulties with finding vantage points for installing the cameras, and the additional time required to view and extract data. The former problem was overcome by using adjacent office buildings with windows overlooking the sites, but at the present time there seems to

be no other alternative than to spend a great deal of time to reduce data manually from video tapes.

Finally, cycle times, types and length of phases, intersection geometries and other relevant features were recorded during subsequent field trips.

Name of Intersection	Number
Côte Ste. Catherine-Côte Des Neiges	1
Rene Levesque-Beaver Hall Hill	2
Rene Levesque-Guy	3
Rene Levesque-Jean Mance	4
Rene Levesque-Peel	5
Rene Levesque-St. Lawrence	6
Rene Levesque-St. Urbain	7
Rene Levesque-University	8
Sherbrooke-Guy	9
Sherbrooke-Peel	10

Table 2.1 List of the Intersections

The following data were carefully extracted from the video tapes.

1. Pedestrian flow in each arm of intersection during each phase.

2. Vehicle turning movements during each phase.
3. Pedestrian/vehicle conflicts in each arm of intersection during each phase.
4. Pedestrian walking times across each arm.

The average walking times were computed from approximately 25 randomly chosen pedestrians crossing each arm in platoons and alone. From these data, it was evident that the average walking speeds at some sample sites are considerably lower than the average of 4 to 4.5 ft/sec suggested in handbooks. The behavior of pedestrians such as jay-walking etc. also varied from site to site.

2.3 DATA ANALYSIS

Data were grouped into the vehicular and pedestrian flows on each arm and the total number of vehicles and pedestrians crossing the intersection per cycle. The number of pedestrian conflicts were also considered for each arm of the intersection. The cycle time for each intersection was approximately 70 seconds. However, intersections were different in terms of the signal phasing configurations.

Next, the data were classified according to three time intervals ie. per cycle, five-minute, and 15-minute. The

grouped data (vehicle flow, pedestrian arrival and conflict occurrence rates) were tested to determine the distribution of each data set. The analyses were carried out on an IBM PS 2/70 using Lotus 123 and a micro computer statistical package (Minitab). Normal, Negative Binomial and Poisson distributions were tested for goodness-of-fit Chi-Square test at the 95% level of confidence.

The probability distribution of pedestrians arrival rates during the three time intervals considered (cycle, and five minute) were, without exceptions, Normal in form. As for the vehicle flow rates, the Normal distribution appeared to best represent the conditions at most intersections, however, some intersections also showed accordance with Poisson distribution. The reason for this can be explained by the fact that the traffic signals were synchronized for the vehicle flow on the east-west direction. This forced vehicles to arrive at the down stream intersection in platoons. The Figures 2.1 and 2.2 illustrate the pedestrian and vehicle arrival rates which are Normally distributed.

The analysis of flow rates showed that 80% of the time the maximum 15-minute pedestrian flow occurred either in the first or last 15-minute of the noon hour flow. The maximum 15 minute flows of pedestrians and vehicles also showed strong relationships to their respective total hourly flows.

The equations designated by "a" below are the regressions of the previous relationships that was forced through origin because the t-ratio of the constant was low enough to be ignored.

$$(2.1) \quad \text{TOTALVEH} = 3.409 \text{ QVEH}_{\text{max}} + 332.09$$

$$R^2 = 0.95$$

$$t(\text{for constant}) = .097$$

$$(2.1a) \quad \text{TOTALVEH} = 3.84 \text{ QVEH}_{\text{max}}$$

$$(2.2) \quad \text{TOTALPED} = 3.705 \text{ QPED}_{\text{max}} - 45.684$$

$$R^2 = 0.991$$

$$t(\text{for constant}) = -0.16$$

$$(2.2a) \quad \text{TOTALPED} = 3.648 \text{ QPED}_{\text{max}}$$

The five-minute maximum pedestrian flows behaved in the same manner as the maximum 15-minute flows of vehicles and pedestrians. The five-minute maximum pedestrian flows as shown below can be used to estimate the total hourly flows. However, the maximum-five minute flow occurred at different times within the 15-minute when the maximum flow occurred. In general, it was also the first or the last five-minute in the maximum 15-minute period.

$$(2.3) \quad \text{TOTALPED} = 8.584 \text{ FPED}_{\text{max}} + 303.787$$

$$R^2 = 0.947$$

$$t(\text{for constant}) = 0.505$$

$$(2.3a) \quad \text{TOTALPED} = 9.564 \text{ FPED}_{\text{max}}$$

Where;

TOTALVEH = Peak-hour Vehicle Volume.

QVEH_{max} = Maximum 15-minute Vehicle Flow.

R² = Coefficient of Determination.

TOTALPED = Peak-hour Pedestrian Volume.

QPED_{max} = Maximum 15-minute Pedestrian Flow.

FPED_{max} = Maximum Five-minute Pedestrian Flow.

CHAPTER 3

METHOD OF CONFLICTS APPLIED TO PEDESTRIAN SAFETY

The major drawback of the conflict approach for assessing safety is that the perception of the accident potential of a conflict is subjective. Nevertheless, the ability to describe the expected number of conflicts in terms of vehicle and pedestrian movement characteristics, such as speed and volume, as well as the fact that these characteristics are easily observable, provides an the opportunity to overcome some difficulties associated with accident data.

The concept of traffic conflicts which was proposed over 20 years ago but never received much attention as a potential tool for analysis of pedestrian safety, has been given some validity by Davis, et al. (1988). One of the primary advantages of this technique is that estimates of surrogate variables based on small data samples can be used to identify the hazardous locations.

The Traffic Conflict Technique (TCT) has also been used by several researchers to perform safety analyses in instances where the accident data are inaccurate. Van Den Hondel et al. (1980), for example, found that it is possible

to use conflicts for identifying hazards, as well as for predicting accidents. The relation between conflicts and accidents suggest that one could expect greater probability of accidents from increased conflicts and/or near misses.

Agent (1976) has suggested that there is a relationship between conflicts and accidents, and that the addition of exclusive left turn phases significantly reduces the number of left turn accidents involving vehicles only.

Spicer (1972) has also found that at any given intersection, the increase in traffic activities increases the number of conflicts between vehicles and subsequently the number of accidents. A year later, the same author [Spicer (1973)] found good correlation between serious (primary) conflicts and accident injury data. He noted that in identifying hazardous locations, the traffic conflict data at an intersection in a short time can complement accident data taken over a longer period of time.

The fundamental difficulties with the TCT are the definition of conflicts and the accurate observation of the defined conflicts. Numerous definitions have evolved from previous researchers. For example, Allen and Shin (1977) have taken the number of times that the break lights of vehicles go on as a measure of the number of conflicts. While this is an easily defined feature, the data may be

distorted due to differences in driver behavior. However, if the definitions can be clarified and the behavior can be observed without much difficulty, this approach has enormous potential for supplementing the information needed for safety management and decision making.

This chapter describes the application of the traffic conflict technique for identifying intersections having a higher than "normal" probability of experiencing pedestrian related accidents (or conflicts). Empirical relations between the expected conflicts and easily observable traffic parameters are derived. These relations show that short-term or sample data can be used effectively to explain the long-term safety implications.

3.1 DEFINITION OF CONFLICTS

For the purpose of this study a pedestrian conflict was defined as: a traffic event involving one or more pedestrians with one or more vehicles, in which one or both have to perform some typical or unusual action, such as a change in direction or speed, that places the other user in jeopardy of a collision unless an evasive maneuver is undertaken. This definition evolved from Glauz and Migletz (1980)'s definition of conflicts between vehicles.

The traffic conflicts were identified and categorized as follows:

1. The pedestrian(s) and vehicle(s) have to cross each other's path in a fashion that one or more has to take evasive action in order to avoid collision.

2. Evasive actions are sudden changes in the speed or direction of travel. (for vehicles: braking, lane change and acceleration, and for pedestrians: stopping, running and lateral movement to avoid traffic)

3. Conflicts are categorized as primary if the evasive actions are taken at a distance less than three meters before the possible collision point. If the distance is greater than three meters it is categorized as a secondary conflict.

3.2 MODEL DEVELOPMENT

3.2.1 Data Preparation and Analysis

The vehicular flows in each approach arm were summed and expressed in terms of vehicles per hour, and were classified by direction of travel with respect to each arm (eg. right turning, straight through and left turning vehicles). The pedestrian flows in each arm were also summed during the same

interval. Then, the number of the pedestrian conflicts were classified with respect to direction of travel of vehicles, and were expressed as occurrences per hour.

Since, 1985-1987 the accident data of Montreal indicates that pedestrian accidents occur mostly during turning. The following three classes of conflicts as shown in Figure 3.1 were investigated in detail:

1. those between the pedestrians and left turning vehicles (LC);
2. those between the pedestrians and right turning vehicles (RC);
3. those between the pedestrians and vehicles traveling straight through (SC).

During data collection, it became evident that in addition to the frequency of pedestrian crossing and vehicles turning, permitted pedestrian green, and intersection geometry have a significant influence on conflicts. The extent of these influences were verified using weighted stepwise multiple regression analysis. The variables used in the regression analyses are:

- (i) Clearance time(seconds).
- (ii) Pedestrians' hourly flow.
- (iii) Volume of left turning vehicles.

- (iv) Pedestrian green time (seconds).
- (v) Average walking time (seconds).
- (vi) Vehicle green time (seconds).
- (vii) Volume of opposing vehicles.
- (viii) Volume of right turning vehicles.
- (ix) Total approach volume at intersection.
- (x) Total pedestrian volume at intersection.
- (xi) Average clearance time (sec).

Since, a vehicle and a pedestrian has to be present at the same time in order to have a conflict, it was decided to include a variable that has no contribution to the number of conflicts when the number of pedestrians and/or vehicles is zero. Thus the product of the number of pedestrians and vehicles is included as an explanatory variable. Moreover, since this variable has a very large numerical value, its square root was used.

3.2.2 Left Turning Conflicts (LC)

Compared to other explanatory variables considered, pedestrian and vehicle volumes, as well as clearance time were able to explain a large portion (67%) of the expected conflicts as given by expression 3.1 below.

The clearance time (CT) is defined as the difference between the permitted green (walk) time and the minimum time

required to cross the arm at the observed average walking speeds.

$$(3.1) \quad LC = 0.85 - 0.0467 CT + 0.0161(P_L Q_L)^{0.5}$$

where;

CT= Clearance time(seconds).

P_L= Pedestrians volume crossing left turning vehicles.

Q_L= Volume of left-hand turning vehicles' hourly flow.

Predictor	Coef.	t-Ratio	Significance of t-test (two tail)
Constant	0.85	0.78	0.439
CT	-.0467	-0.95	0.348
(P _L * Q _L) ^{0.5}	0.016	8.40	0.000

$$R^2 = 67.1\%$$

$$R^2(\text{adj}) = 65.3\%$$

Table 3.1. Estimation results of equation 3.1.

It was also of interest to find the effect of the number of the pedestrians and vehicles separately on conflicts. Expression (3.2) shows that the number of left turning vehicles has a much greater influence than pedestrians. The large contribution of the left turning vehicles could be due to the fact that these vehicles have to share the green time with opposing flows and as a result, they accept smaller gaps for crossing the opposite flow. Thus, the turning speeds and the potentials for conflict are greater. Further, from

expression (3.2) it is evident that the number of pedestrians make a very small contribution to the number of conflicts. This demonstrates that considering the the pedestrian and left-hand turning vehicles as two separate variables may not help in obtaining a better relationship for left turning conflicts.

$$(3.2) \quad LC = 1.8 + 0.031Q_L + 0.18 \times 10^{-3}P_L + 0.073 \times 10^{-2}Q_0 - 0.075CT$$

$$R^2 = 74.0\%$$

where;

Q_0 = Opposing vehicles' hourly flow.

The drivers tend to pay more attention (less infringements or crossing of pedestrians' paths) to pedestrian right of way when the left-turning interval is longer or the green time is greater, than when the time is insufficient to empty the turning queue. The above relation shows that the number of conflicts between the left turning vehicles into a given arm and the pedestrians crossing that arm is influenced by the volume of vehicles opposing the turning vehicles this could be regarded as a restriction to turning as mentioned earlier. One should, however, consider the situation carefully before offering an explanation. For instance, as the opposing volume increases, the number of left-turning vehicles should diminish, unless there is an

exclusive left-turning phase. Therefore, in the absence of exclusive phases, conflicts between the pedestrians and vehicles should ideally diminish at high opposing volumes, even though the conflicts between vehicles may increase.

The observed data also confirm the assumption that left turning conflicts at any given intersection is a Poisson random variable. Figure 3.2 shows a sample of the observed and expected number of left turning conflicts. The Poisson distribution parameter which is different from one intersection to another can be estimated from any of the regression models discussed above.

3.2.3 Right Turning Conflicts (RC)

Right turning vehicle and pedestrian occurred conflicts between pedestrians crossing an arm of the intersection and the vehicles making a right turn into the same arm. Thus, it was logical to assume that the same variables as in expression (3.1) would be able explain the right turning conflicts.

Surprisingly, however, the regression model derived (expression 3.3 below) indicates that conflicts increase with permitted green time. A possible explanation for this is that green time is basically the exposure time (to right

turning vehicles) and hence, an increase in this variable would increase the number of conflicts

$$(3.3) \quad RC = - 0.87 + 0.02 (Q_R P_R)^{0.5} + 0.031 \text{ GRT}$$

where;

Q_R = Volume of vehicles turning right.

P_R = Pedestrians volume crossing right turning vehicles.

Predictor	Coef.	t-Ratio	Significance of t-test (two tail)
Constant	-0.87	0.32	0.754
$(P_R * Q_R)^{0.5}$	0.02	6.22	0.000
GRT	0.031	-0.24	0.815

$$R^2 = 52.1\%$$

$$R^2(\text{adj}) = 50.0\%$$

Table 3.2 Estimation results of equation 3.3.

Since pedestrians and right turning vehicles share the same green time, expression (3.3) seems logical. That is, the increase in the duration of green time will increase the exposure. Similarly, the shared green time which by itself is a function of the protected pedestrian green time (wherever available) has the same effect on the the total number of conflicts.

As for the variability, it was found to be a Poisson random variable similar to the left turning conflicts as

shown in Figure 3.3. The distribution parameter is once again a random variable estimated through the regression models.

3.2.4 Straight Through Conflicts (SC)

These conflicts were between the vehicles traveling straight through and the crossing pedestrians. It is rather difficult to provide a quantitative or mathematical explanation for this type of conflict, but, a qualitative explanation can be postulated.

Most of these conflicts, occurred during the illegal crossing (jay-walking) of pedestrians. As reported by Seneviratne and Javid (1988), 40% of Montreal's pedestrian accidents in 1987 resulted from persons crossing without the right of way. The remainder of these conflicts resulted from pedestrians crossing the major arms of intersections having insufficient green time.

The observed data showed that the intersections with relatively lower pedestrian volumes had a higher proportion of straight-through conflicts. Intersections, with the total pedestrian volume of less than two thousand pedestrians in one hour had considerably higher rates of conflict (straight) per total pedestrians than the busier intersections. From a behavioral point of view, it seemed that this was due to

pedestrians' feeling of guilt, and that the delay is perceived to be less when one is among many persons (a platoon) than when one is alone. Moreover, when there are many pedestrians, platooning permits only the leaders to cross and if one is at the back of the pack, it is difficult to move up unless the leaders cross without the right of way. Therefore, at intersections with the same volume of traffic, it is likely that the proportion of persons crossing without right of way will be lower if the pedestrian volumes are high, than if they are low.

3.2.5 Total Conflict (C)

The total number of conflict at an intersection provides an overall indication of the level of safety. For this reason, the relation between the total number of conflicts and other traffic activities was investigated. Expression (3.4) was obtained after regressing the total approach volume of traffic, the total pedestrian crossings and the average clearance time against the total number of pedestrian conflicts.

$$(3.4) \quad C = 14.5 + 0.0182 (Q P)^{0.5} - 0.739 ACT$$

where;

C = Total conflict at intersection (per hr).

Q = Total approach volume at intersection (per hr).

P = Total pedestrian volume at intersection (per hr).

ACT = Average clearance time (sec).

Predictor	Coef.	t-Ratio	Significance of t-test (two tail)
Constant	14.5	0.62	0.56
ACT	-0.739	-0.80	0.454
(P Q) ^{0.5}	0.0182	4.96	0.003

$$R^2 = 84.2\%$$

$$R^2(\text{adj}) = 78.9\%$$

Table 3.3 Estimation results of equation 3.4.

As shown in Table 3.3, the effect of the constant and the ACT on the equation is rather minimal. Therefore, it was decided to drop the ACT variable.

$$(3.5) \quad C = -2.851 + 0.0193 (P Q)^{0.5}$$

Predictor	Coef.	t-Ratio	Significance of t-test (two tail)
Constant	-2.851	-0.32	0.758
(P Q)	0.0193	5.75	0.000

$$R^2 = 82.5\%$$

$$R^2(\text{adj}) = 80.0\%$$

Table 3.4 Estimation results of equation 3.5.

From expression (3.5), it is clear that the exposure variable can explain over 80% of the variation in conflicts. Moreover, the effect of the constant is negligible and it turns out that the expected conflicts at any given

intersection in the sample is a basic power function of the of the product of the pedestrians and traffic volumes of the form given by expression 3.6 below.

$$(3.6) \quad C = 0.037 \langle Q P \rangle^{0.45}$$

$$R^2 = 80.0\% \quad R^2(\text{adj}) = 77.0\%$$

The occurrence rates of the total pedestrian conflicts were also tested and like the rates of LC and RC they were also Poisson distributed. Figure 3.4 illustrates the latter.

From the analyses, it is evident that the square root of the product of number of the pedestrians and number of conflicting vehicles, is the most significant contributor to the number of the conflicts (see Tables 3.1, 3.2, 3.3, and 3.4). Other factors such as green time and the average walking time had relatively minor effects on the production of conflicts. The constants of the equations discussed in this chapter (see Tables 3.1 to 3.4) all had small t-ratios (with consideration of proper degrees of freedom) and they also had larger p values than other variables in the equations. These suggest that the hypotheses that the constants (intercept) of the regression equations are zero is very likely to be accepted.

CHAPTER 4

ESTIMATION OF PEDESTRIAN AND TRAFFIC FLOWS

Inasmuch as traffic accident records, pedestrian and traffic volume records of many local transportation agencies are incomplete or non-existent, even the alternative approaches including the conflict technique are of no real value to the traffic engineer for managing safety. In this chapter, a methodology for estimating pedestrian and traffic flow from the collected sample data is proposed for situations where data are unavailable.

4.1 PEDESTRIAN FLOW

The absence of flexible analytical tools, the costs associated with manual data collection, and the lack of proven mechanical or electronic data collection techniques have forced authorities to shy away from the question of pedestrians. Once the technology is fully developed, and automated data gathering techniques become easily accessible, local authorities will be able to take advantage of several statistical techniques for estimating pedestrian flow at a low cost. In this section it is shown that sample data, experience of the analysts (subjective judgement), and/or estimates from predictive models, can be combined according

to Bayesian statistical rules to estimate flow needed to analyze the supply and quality of service, and safety of pedestrian facilities.

There have been attempts to formulate standard mathematical as well as qualitative models to characterize the traffic and pedestrian flows. Greenshields (1943), & Greenberg et. al (1958), have developed the vehicular traffic flow models, and in the area of pedestrian movement researchers such as Fruin (1971), Navin & Wheeler (1968), and O'Flaherty and Parkinson (1972) have concentrated on evaluating walkway capacities and levels of service. Much of the work on the pedestrian demand side involved the development of multiple regression type predictive models, Rutherford (1979), Pushkraev and Zupan (1971) and Benham and Patel (1971), based on land-use variables at specific sites. However, as pointed out by Davis et al. (1989), the transferability and long-term validity of these models are not clearly demonstrated. Even where these two problems can be overcome, the extensive input data requirements limit their practicality. Alternatively, Davis et al. (1989) have proposed expansion models for crosswalk volumes, on the basis of data collected at eight sites in Washington D.C. They have found that hourly pedestrian volumes can be predicted from counts obtained from time periods as small as five-minutes. Haynes (1977) has shown that the estimation errors can be minimized by selecting 10 to 15-minute counts, and

that the reduction in the margin of error diminishes for count intervals greater than this.

4.2 RELATION BETWEEN RATE OF FLOW AND VOLUME

From the research and experimental work performed over the last two decades, one can be fairly confident in estimating the hourly or daily pedestrian volumes from the rates of flow. However, the strength of the relation between the two variables is:

- (1) very much site dependent, and
- (2) influenced by the length and position of the time interval used in rate of flow calculations.

For instance, the logarithmic relations obtained by Davis et. al. (1988) are valid only for sites with a certain range of volumes, since the sample sites were selected according to volume. Thus, one should take care in using these models to evaluate sites carrying volumes above or below the specified range. In other words, it means that a global model that will be valid over the entire geographical area will not have the same predictive accuracy as multi-regime models or models fitted to flow data disaggregated into several regimes according to magnitude, as proposed by Seneviratne (1984).

With regard to the second factor influencing model accuracy, the ideal or optimal sampling interval may not always be the middle interval during the hour in which the volume is to be estimated. Contrary to Davis et al. (1988), this study found that the strongest correlation exists between the highest 15-minute flow during an hour and the volume in that hour. The highest 15-minute flow occurred almost equally during the first and the last 15-minute interval during the hour, due to the short surges that occur when office employees leave for their lunch break at noon, or return at the close of the hour. This phenomenon could be true during most peak periods, as well as off-peak due to the general tendency to have appointments or to make trips at or close to the hour. The time of day when the sampling should be done is also important.

Thus, there are some important issues still to be resolved before one can develop reliable expansion models. The first is the optimal length of the sampling interval for the rate of flow calculations (ie. one-minute, five-minute or 15-minute). Secondly, once the length of the interval is chosen, it must be determined at which stage (position) in the analysis period the sample should be taken (ie. first quarter, second quarter and etc.). The first issue can be reasonably assumed as resolved since Haynes (1977) has shown statistically that a 10 or 15-minute rate of flow would minimize the estimation errors, regardless of the site. On

the other hand, without extensive data, one cannot be certain about the position of the sampling interval which would derive the expansion model with the highest predictive capability.

Even if we assume, for simplicity, that we are able to develop a model from data previously collected over long periods, the expanded values would depend on the input values of the independent variable (the short-term count). For instance, suppose the existing expansion model could estimate hourly volume from a five-minute flow during the middle of that hour due to the variations in flow from one time period to another, the five-minute flow taken on one day could differ from the count taken the next day or the week in the same time interval. This would obviously cause a difference in the estimated volume. Therefore, one should ideally use the most likely (expected) five-minute flow, and given that we are attempting to maximize our information from the limited data available rather than collecting data over many five-minute weeks, the Bayesian approach enables us to obtain the best estimate of the expected flow.

4.3 VARIATION OF PEDESTRIAN FLOW

Due to the greater interaction between pedestrians who have a tendency of walking side by side in pairs or groups, as well as the trip generation rates which are influenced by

the capacities of the transportation modes and traffic signals, pedestrian flows are highly irregular. Studies by Haynes (1977), Seneviratne & Morrall (1983), and Pushkarev & Zupan (1971) have revealed that flow during small intervals are virtually irreproducible from one day to another. Thus, decisions based on average flows, estimated from small samples taken over short time intervals, are likely to be sub-optimal. However, one can employ certain statistical tools to combine sample data with subjective judgement based on her/his experience and/or historic data, to obtain the maximum likelihood estimates of the short term flow. These estimates in turn would be the input for the expansion models.

The most appropriate statistical tool for a particular situation depends entirely on the probability distribution of the flow, which tends to follow a certain regular pattern during sufficiently large time intervals. For instance, even though very short term fluctuations are virtually unavoidable and of less significance to planners and engineers, Haynes (1977) found that at mid-block locations, the one-minute flow is a Normal random variable. Seneviratne & Morrall (1983) found that a similar distribution fits the 15-minute flow during morning, noon, and afternoon peaks.

After fitting three different distributions (Normal, Poisson, and Negative Binomial), it was found that the five-

minute flow at intersections can also be reasonably approximated by a Normal distribution as shown in Figure 4.1. Moreover, Seneviratne (1983) has shown that the means of the five-minute flow during one hour at similar intersections as well as the means of the 15-minute flow at comparable (in terms of adjacent land use) mid-block sites are Normally distributed. In other words, if sample site i has a mean flow of m_i ($i = 1$ to j), the distributions of m_i is Normal in form with mean m' and standard deviation s' .

4.4 BAYESIAN ESTIMATES OF EXPECTED FLOW

The Bayesian approach enables one to refine the estimates of the mean (expected) flow, m_i , obtained from a few counts at site i . For instance, if the analyst has experience with similar sites or he/she can find some previously recorded data to calculate the expected flow and standard deviation of flow, m' and/or s' , the Bayesian approach can be followed to combine this information with m_i and s_i to arrive at the maximum likelihood estimates of the mean flow m'' , and the variance of flow, s''^2 . This approach has had many applications in the field of Geotechnical Engineering, Benjamin and Cornell (1970), where the testing is costly and the design characteristic (soil stability) is highly variable like pedestrian and traffic flow. Yet, it has been used to a much lesser extent in Transportation Planning, e.g. Mahmassani & Sinha (1981).

In this section an example is used to illustrate the application of Bayesian theory for estimating and updating pedestrian flow at a given site.

The basic procedure contain three simple steps. The first step involves finding or assuming the **prior** distribution of the random variable. The random variable in this case is the pedestrian flow per unit time during the period of analysis. The prior distribution is defined as the distribution of flow per unit time that existed before or what the analyst expected at that site. The prior distribution parameters, m' and s' , are based on data collected previously or the analyst's experience with similar sites. According to the data, it is assumed that for any site i , the distribution is Normal in form, and that the parameters (m' & s') are known.

The next step is to derive the **sampling** distribution parameters. In this case, it is assumed that the sample data are also Normally distributed with $N(m_1, s_1)$. For example, suppose one is interested in the volume during P.M. peak at site i which will be derived from expanding the mean 15-minute flow. Since the objective is to minimize data collection efforts, one could assume that m_1 is simply equal to any one 15-minute count during the hour or the mean of n one-minute counts during a randomly chosen 15-minute observation period within the P.M. peak.

If the form and parameters of the prior and sample distributions are known, Howard & Raiffa (1961) have shown that the **posterior** or **updated** distribution parameters can be derived using terminal analysis. Compared to the sample or prior distribution parameters, the updated posterior parameters are more likely to be closer to the true or population parameters. Thus, if one can expand the posterior estimate of the 15-minute flow in the expansion model, as opposed to m_i as is traditionally done, it will lead to a more accurate measurement over time.

When the prior and sample distributions are both Normal in form, Howard & Raiffa (1961) found that the following relationships hold between the posterior distribution parameters and the prior and sample parameters.

$$(4.1) \quad m'' = \frac{\left[\frac{m'}{(\sigma')^2} \right] + \left[\frac{m_i}{s_i^2/n} \right]}{\frac{1}{(\sigma')^2} + \frac{1}{(s_i^2)/n}}$$

$$(4.2) \quad s'' = \left[\frac{1}{\frac{1}{(\sigma')^2} + \frac{1}{(s_i^2)/n}} \right]^{\frac{1}{2}}$$

where n , m_i , and s_i are sample size, mean and standard deviation respectively of the **prior** distribution at site i .

The distribution parameters of the **prior** and **posterior** distributions are denoted by $[m', s']$ and $[m'', s'']$ respectively.

4.5 NUMERICAL EXAMPLES

The objective of this experiment is primarily to test the advantage of using m'' over m_1 . Moreover, it was of interest to inspect the effect of increasing the number of observation periods (n) for the difference between m'' , m_1 , as well as m' .

The distribution of means of five-minute flow during noon-hour from 10 different intersections in Montreal followed a Normal distribution with a mean of 188 persons/five-minutes. The standard deviation of the flows was 102 persons/five-minute. These two values, which are based on 12 five-minute counts at each site, are the prior distribution parameters m' and s' .

The five-minute flow at two test intersections were observed for a period of one hour during the noon peak-hour (12:00 h to 13:00 h). These data are used to derive the sample distribution parameters, or m_1 (persons/five-minute) and s_1 (persons/five-minute) for each intersection. Different sample sizes were used to compute these parameters:

(ie. $n = 1, 2, 3, \dots, 12$ -five minute counts) as shown in Tables 4.1 and 4.2.

Intersection I:

The true five-minute mean based on twelve counts at this intersection was 74 persons/five-minutes with a standard deviation of 11 persons/five-minutes.

It is obvious that the mean and standard deviation of flow at the test intersections do not fall into the same class as the 10 intersections in the original sample in terms of the because of the magnitudes. It meant that this test site cannot be considered as coming from the same population, even though, they had the same land use. Thus, the prior parameters were extracted from a set of four intersections from the original sample having the same range of five-minute flows. Thus, the prior distribution parameters were taken to be:

$$\mu' = 73$$

$$\sigma' = 7$$

In order to examine the extent to which m_i approaches the average five-minute pedestrian flow, different sample counts, n , were considered. Subsequently, the posterior parameters were calculated using expressions (4.1) and (4.2) and are given in Table 4.1.

data set	n	m_i	s_i	m''	s''
1	4	77	12	75	5
2	4	76	10	75	5
3	3	69	11	71	5
4	3	71	10	72	4
5	3	79	12	76	4
6	2	78	7	76	4
7	2	64	10	68	5
8	2	69	10	71	5

Table 4.1 Comparison of Sample and Posterior Values.

Compared to m_i , m'' in each case is closer to the observed mean five-minute flow of the given hour, as illustrated in Figure 4.2.

Intersection II:

The mean five minute pedestrian flow was calculated for the second test intersection. The observed five-minute mean flows and standard deviations were 174 persons/five-minute and 26 persons/five-minute respectively. The prior parameters were obtained from a different set of five intersections from the original having the same range of flow.

$$m' = 170$$

$$s' = 26$$

Different n values were considered once again to calculate m_i and s_i . Similarly, the posterior parameters were calculated using expressions (4.1) and (4.2). Results are given in Table 4.2.

data set	n	m_i	s_i	m''	s''
1	4	102	13	121	6
2	4	155	43	166	10
3	3	185	25	180	12
4	3	130	17	146	8
5	2	198	18	182	9
6	2	196	18	188	11
7	2	144	34	165	11

Table 4.2 Comparison of Sample and Posterior Values.

As seen from Figure 4.3, once again the empirical Bayesian estimates are closer to the hourly mean. Figure 4.3 illustrates that the posteriors are closer approximations regardless of the time within the hour that the samples were taken. Several values of posterior and sample parameters for the same values of n in Figure 4.3 are those for different time intervals within the same hour.

As for vehicular flow, a third intersection with a mean of 228 vehicles/five-minute and standard deviation of 18

vehicles/five-minute, was used to verify the application of Baye's procedure for estimating flow.

The prior parameters were:

$$m' = 224$$

$$s' = 15$$

The Bayesian estimates with different sample size are shown in Table 4.3.

data set	n	m_j	s_j	m''	s''
1	4	229	12	228	6
2	4	240	18	235	8
3	4	217	17	219	7
4	4	199	53	219	13
5	3	229	19	227	9
6	3	242	16	237	8
7	3	232	16	229	8
8	3	215	20	218	9
9	2	236	6	235	4
10	2	243	20	234	10
11	2	237	17	232	6
12	2	210	11	213	7
13	2	233	10	231	6

Table 4.3 Comparison of Sample and Posterior Values.

Figure 4.4 illustrates the difference between the posterior mean and the observed mean five minute flow.

The foregoing demonstrates that compared to sample means based on a small number of observations, Bayesian estimates are closer to the true (mean) flow. Thus, one can increase the estimation accuracy by using m'' as input variable in expansion models, or any other relations obtained between hourly or longer time periods, as well as shorter time intervals.

The procedure is simple and it minimizes the data collection requirements (ie. requires only a five- or 15-minute count), at the same time leading to a higher accuracy. It can also be used for updating information. For example, assume that next year one need to update the flow data. In this case, the current posterior parameters will act as the prior parameters for next year, we can collect a sample during a similar five-minute interval(s) to obtain the sample parameters. One will note that the next set of posterior parameters (Bayesian estimates) obtained from expression (4.1) and (4.2) will be even closer to the true values than this year's values.

The Bayesian approach can also be used as a routine (annual) updating procedure for all sites. If the last years counts are available, they could be updated with the aid of a very short term sample collection by following the steps previously described.

Given that expansion models can usually explain only a part of the variation, the estimation errors could multiply, unless the input values are accurate. This was illustrated in the numerical examples, where the variability of the short term counts resulted in a difference in estimated and observed volumes. For example, Table 4.4 shows that compared to the posterior five-minute rate of flow, the sample mean five-minute rate of flow is considerably larger or smaller than observed volume.

m'	m_j	m''	$m' - m_j$	$m' - m''$	$d_{\dots} m' - m_j$	$d_{\dots} m' - m''$
228	199	219	29	9	348	108
228	243	234	15	6	-180	-72
170	102	121	68	49	816	588
170	198	182	28	12	-236	-144
74	64	68	10	6	120	72
74	79	71	5	-3	-60	-36

Table 4.4. Comparison of sample and posterior means.

Even when expansion models are unavailable, one can use the Bayesian estimation procedure to derive the required information. For instance, most municipalities may have pedestrian flow data collected during intersection traffic counts in previous years, or they may have performed some additional counts at different sites. These data can be

combined with sample counts to derive updated volumes needed for level of service and safety analysis.

Thus, in summary one can employ the Bayesian approach to estimate flow at new sites or update flow at previously surveyed sites. The basic steps to follow at a new site are:

- (a) Compute from data available for similar sites or assume according to experience, the mean (m') and standard deviation (s') of, for example, P.M. peak volume likely to exist at the site in question.
- (b) Perform a sample count over a short period, for example, one minute flow during 15-minutes, and compute the mean (m_1) and standard deviations (s_1).
- (c) Substitute these values in expressions (4.1) and (4.2) to obtain the expected volume (m'') and standard deviation (s'').

One of the most important rules in utilizing this method is proper selection of the parameters. For example, if the prior parameters used for the analysis are not in the same range as the sample parameters (or from the same population) the estimation errors will be great. In other words, the experience and judgement of the engineer or planner to

properly select similar sites is the most important factor in the performing empirical Bayesian analysis.

CHAPTER 5

APPLICATION OF CONFLICTS TECHNIQUE FOR IDENTIFYING HAZARDOUS SITES

It has been established during several previous studies that there is a direct relation between accidents and conflicts. Thus, locations with high conflicts should be of concern to the traffic engineers. Although the sites with primary conflicts are more likely to experience accidents than sites with secondary conflicts, the latter type which occur more frequently can be a useful indicator of the level of safety.

In the previous Chapter it was found that the total expected secondary conflicts at any given intersection in the study area is basically a power function of the exposure measure PV. Moreover, it was apparent that the conflicts during left and right turning maneuvers occur due to certain deficiencies in the signal timing. Thus, one could use these variables to identify sites which can expect a higher than "normal" number of conflicts.

Due to the random nature of the contributing factors, conflicts may be concentrated within a short time interval or at a small number of locations. Therefore, the number of

conflicts that will be observed at two locations with the same geometric and traffic characteristics may be different. In this case, one needs to use certain statistical criteria to distinguish between safe and unsafe sites because no deterministic model will be able to predict the conflicts or the accidents with certainty.

In Chapter 3, it was shown that regardless of the time period under consideration, the observed conflicts at a given intersection follow a Poisson distribution. On the other hand, the expected conflicts, given by expressions 3.1 to 3.4, indicate that the distribution parameter will be different from one intersection to another. These two statistical models will allow the analyst to identify the sites which have a higher than normal likelihood of conflicts.

This same approach was used by Mahalel et al. (1989) for identifying sites with high concentrations of accidents. Since accident rates are variable over time, they used a homogeneous Poisson process to estimate the critical number of accidents that would occur with a certain predetermined degree of confidence. This critical number or rate of accidents is used as the basis for allocating resources for improving the conditions.

Using the same principal, for any population having an expected conflicts of $\lambda(t)$, the probability of observing c conflicts over a period of time t can be obtained from the Poisson model given below.

$$(5.1) \quad P(c) = \frac{e^{-\lambda(t)} [\lambda(t)]^c}{c!}$$

Expression (5.1) in turn is used to identify the sites which have a probability that the number of conflicts will be greater than some observed value less than the predetermined value c . In other words, as an example, one can set the 95th percentile conflicts as the criteria for comparison, and any intersection whose 95th percentile conflicts is greater than the predetermined value, then that intersection will be identified as a "black spot".

$$(5.2) \quad P \left[Y > c \mid \lambda(t) = Y(t) \right] = \sum_{c=0}^{\infty} \frac{e^{-Y(t)} Y(t)^c}{c!} < \alpha$$

The expected conflicts $Y(t)$ during time interval t is obtained from the empirical relations such as those in Table 3.

The period of study considered in this project is sufficient to classify intersections or identify black spots. Nevertheless, one could conjecture that the same

parameters in expressions 3.1 to 3.4 will explain most of the variation in the conflicts during extended periods of time such as a 12 hour period or 24-hour day. If this is true then one can use expansion models, together with the estimation procedure discussed in Chapter 4, to estimate the input values needed for computing the expected conflicts. Once the expected conflicts values are known, the hazardous sites can be identified on the basis of the predetermined degree of confidence as discussed above.

5.1 NUMERICAL EXAMPLE

The following example will discuss the method. Given that the following data exist for the intersection:

No. of Pedestrian/hour of green = 488
No. vehicle/hour of green = 1790

Substituting in expression (3.5);

Expected No. of conflicts, λ/t , = 18

Assume, that the 95th percentile conflicts or the critical number of conflicts is 20. Thus, one can use expression (5.2) to find the probability that the number of conflicts would be greater than 20 is more than 5%, in which case intersection would be hazardous.

Substituting for $Y(t)$ and C in expression (5.2)

$$P(c > 20) = 0.083 > 0.05$$

Accordingly, it appears that the intersection is hazardous.

CHAPTER 6

CONCLUSIONS

It has been shown that traffic conflict analysis can be an extremely useful tool for complementing traditional accident analysis procedures that use accident statistics. The advantages are greatest in situations where accident data are incomplete or unreliable. The key to the success of this approach, however, lies in the clarity of the definition of conflicts and the ability to collect reliable data. Except for the need to be extremely careful with data collection during the initial model development stages, this approach can be a valuable time saver since it is dependent on reliable data.

The observed pedestrian conflicts at a given intersection were found to be a non-homogeneous Poisson process. The non-homogeneity is a result of the variable nature of the factors influencing the conflicts such as traffic and pedestrian volumes. For example, the pedestrian and vehicle arrival rates were Normally distributed. Nevertheless, the relations obtained between these variables and the conflicts enabled the estimation of the Poisson distribution parameter for a given situation. On the basis of the number of conflicts which can be regarded as critical,

one can determine the relative safety of an intersection or classify it as a black spot or not.

The conflict estimation models were not able to explain all the variation in conflicts. This was due to the fact that the variable did not represent the driving conditions. Some researchers have presented more detailed mathematical models to explain the the relationship of different traffic components and exposure. Nevertheless, they require very large surveys and analyses which are unlikely to be undertaken by municipalities in the foreseeable future.

It was also shown that where data is lacking or unavailable, the conflict model (expression 3.1 through 3.5) parameters can be estimated from small samples. It was shown that the empirical Bayesian approach can be a useful tool for minimizing the errors associated with sample data.

Although this study was limited to the analysis of only during a short period of one hour, the concept can be easily applied to assess long-term safety. Undoubtedly, this would require extensive data, first to establish the relation between conflicts and observable factors, and secondly to develop expansion factors for estimating the conflict model variables. In this exercise, it was shown that there are strong relationships between the maximum five- and 15-minute

flows and peak-hour volume in the case of both of pedestrians and vehicles.

From the observations, it seemed that neither the pedestrians, nor the drivers respected the right of way of the other at all times and would try to clear the intersection with minimal waiting time. Moreover, the wider arms of the intersections had less pedestrian green time. Of course, the pedestrian green time is a result of the cycle times dictated by signal synchronization. Therefore, conflicts can be regarded as inevitable if the primary objective is to minimize traffic delays.

Although it seems that one of the solutions would be to increase protected green time for pedestrians, this aspect needs to be studied in more detail. Nevertheless, when designing or redesigning the signal timing plans, one should examine the possible changes in the number of the pedestrian conflicts. One could also try to seek an optimal range that would be beneficial to drivers as well as pedestrians. At the same time, a road user education program that sensitizing them to the hazards as well as enforcement should be considered.

The heavily used intersections could be studied in detail for the suitability of installing exclusive turning and pedestrian green phases. Furthermore, all red phases can

be employed at the desired intersections to decrease exposure and subsequently the number of conflicts.

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APPENDIX

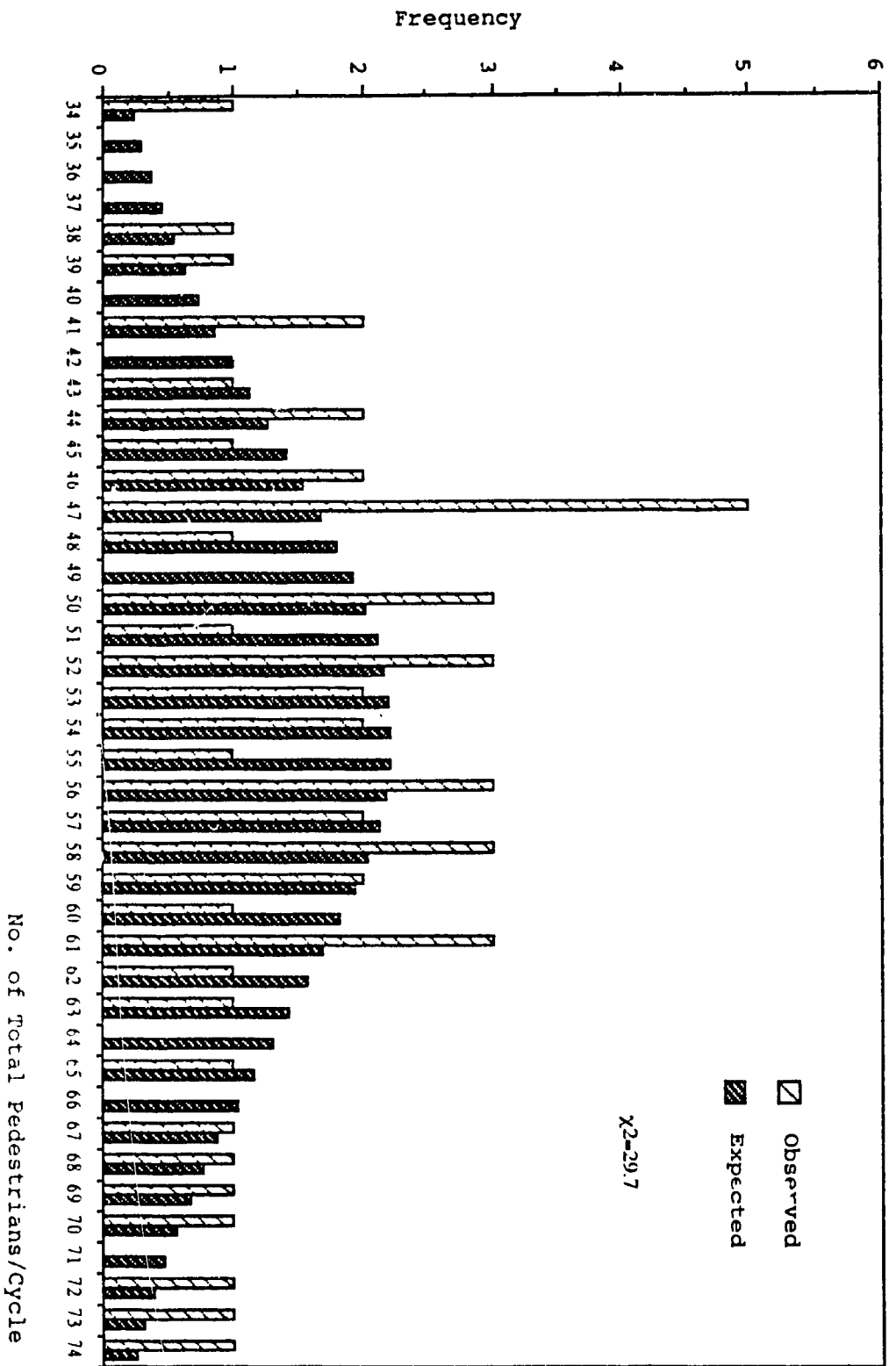


Figure 2.1 Comparison of Observed and Expected No. of Pedestrians.

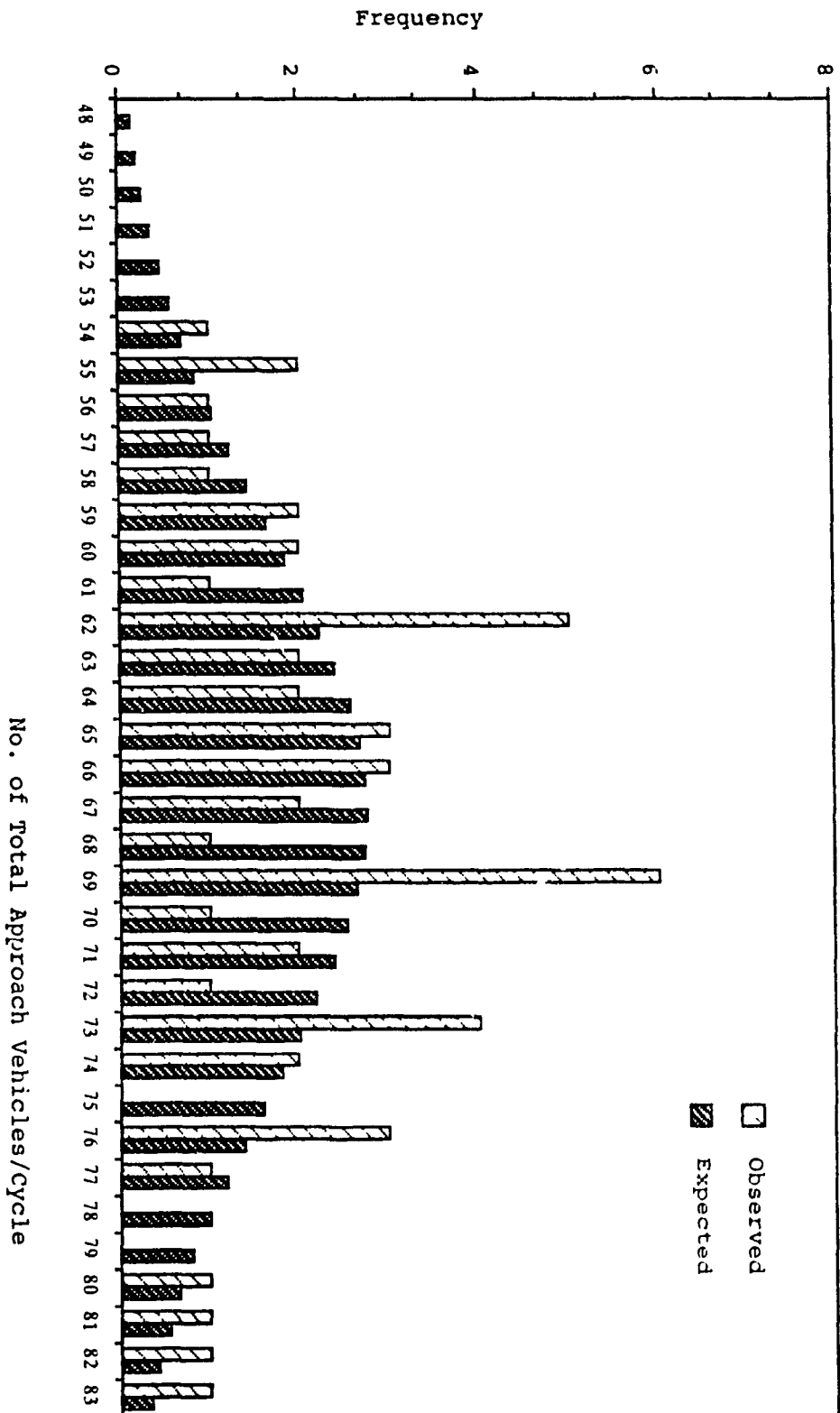
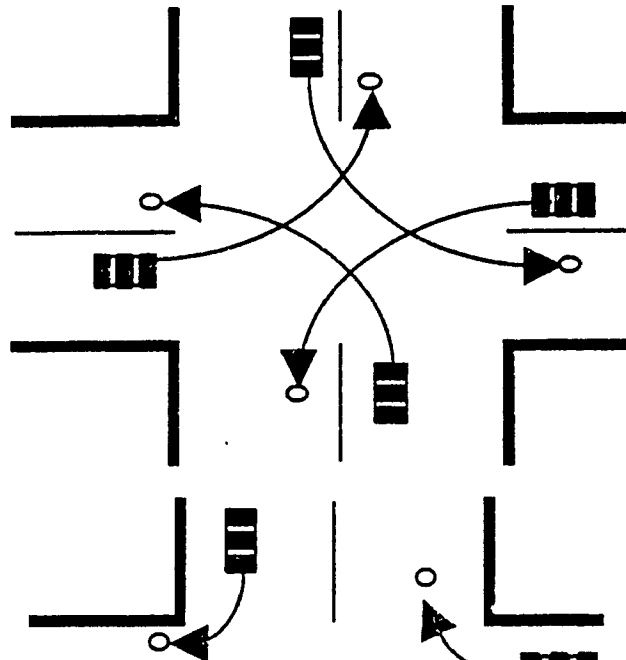
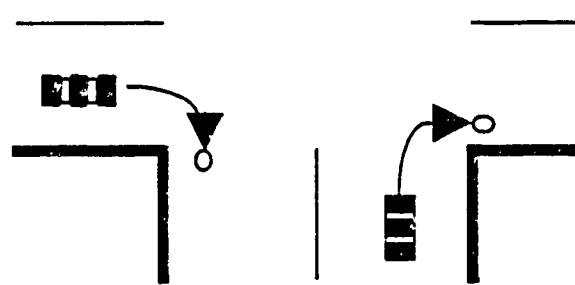


Figure 2.2 Comparison of Observed and Expected No. of Vehicles.

a).
Left
Turning
Conflicts



b).
Right
Turning
Conflicts



c).
Straight
Through
Conflicts

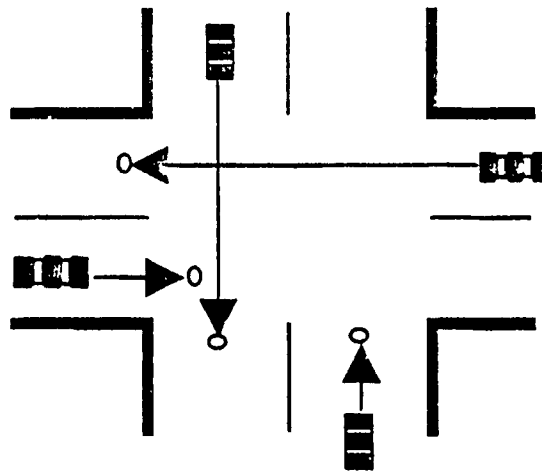


Figure 3.1 Types of Conflicts.

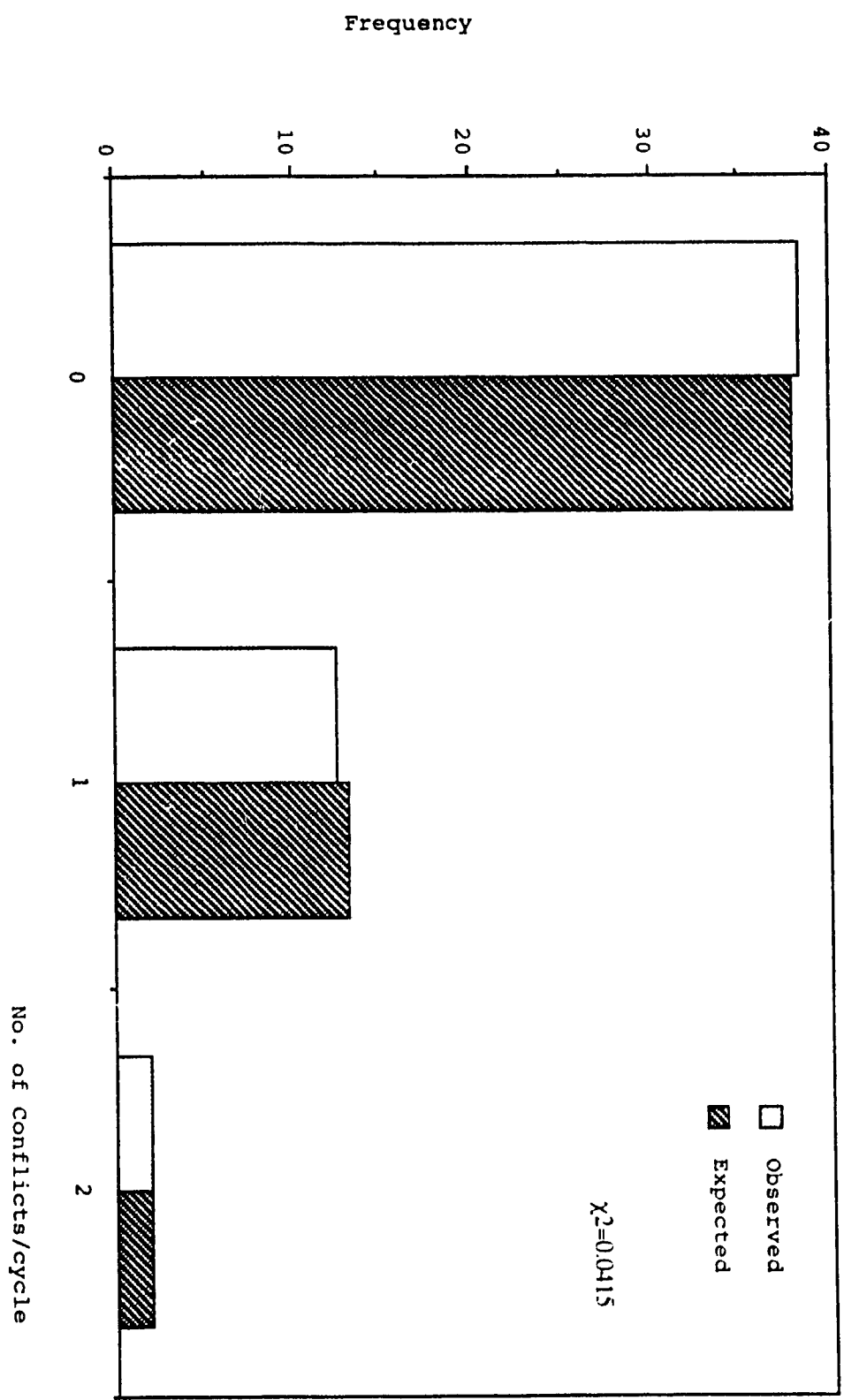


Figure 3.2 Comparison of Observed and Expected No. of Left-Turning Conflicts.

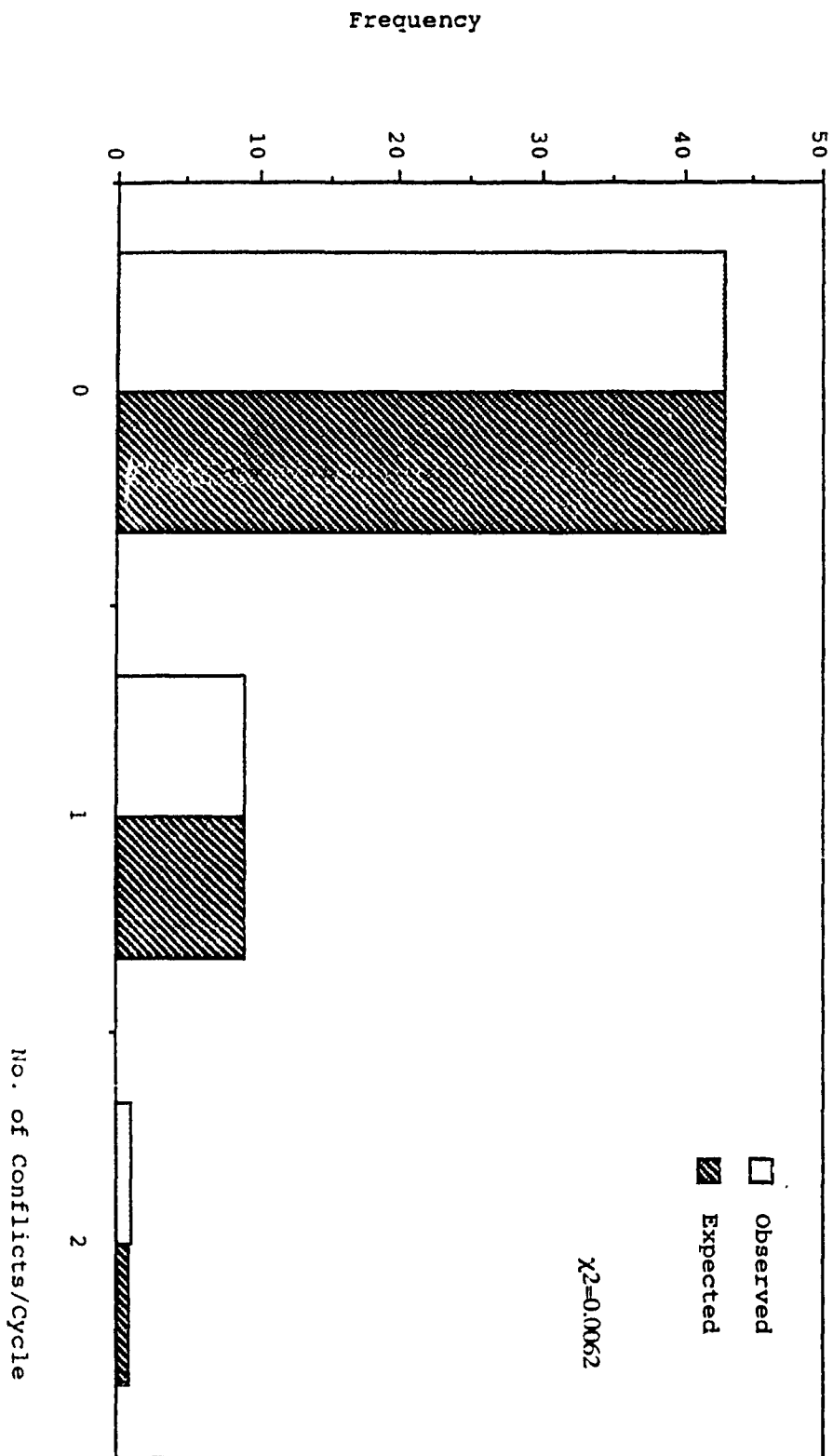


Figure 3.3 Comparison of Observed and Expected No. of Right-Turning Conflicts.

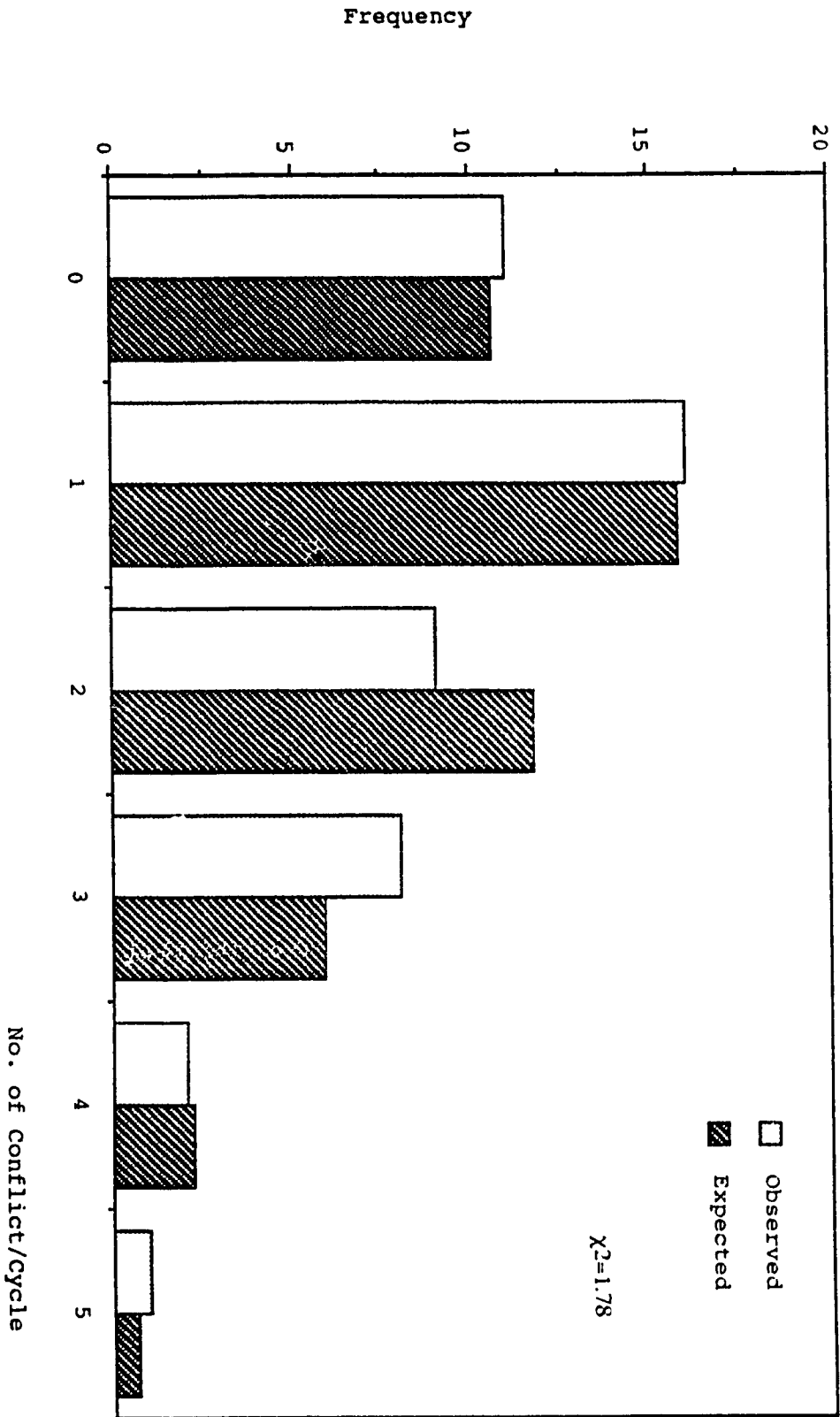


Figure 3.4 Comparison of Observed and Expected No. of Total Conflicts.

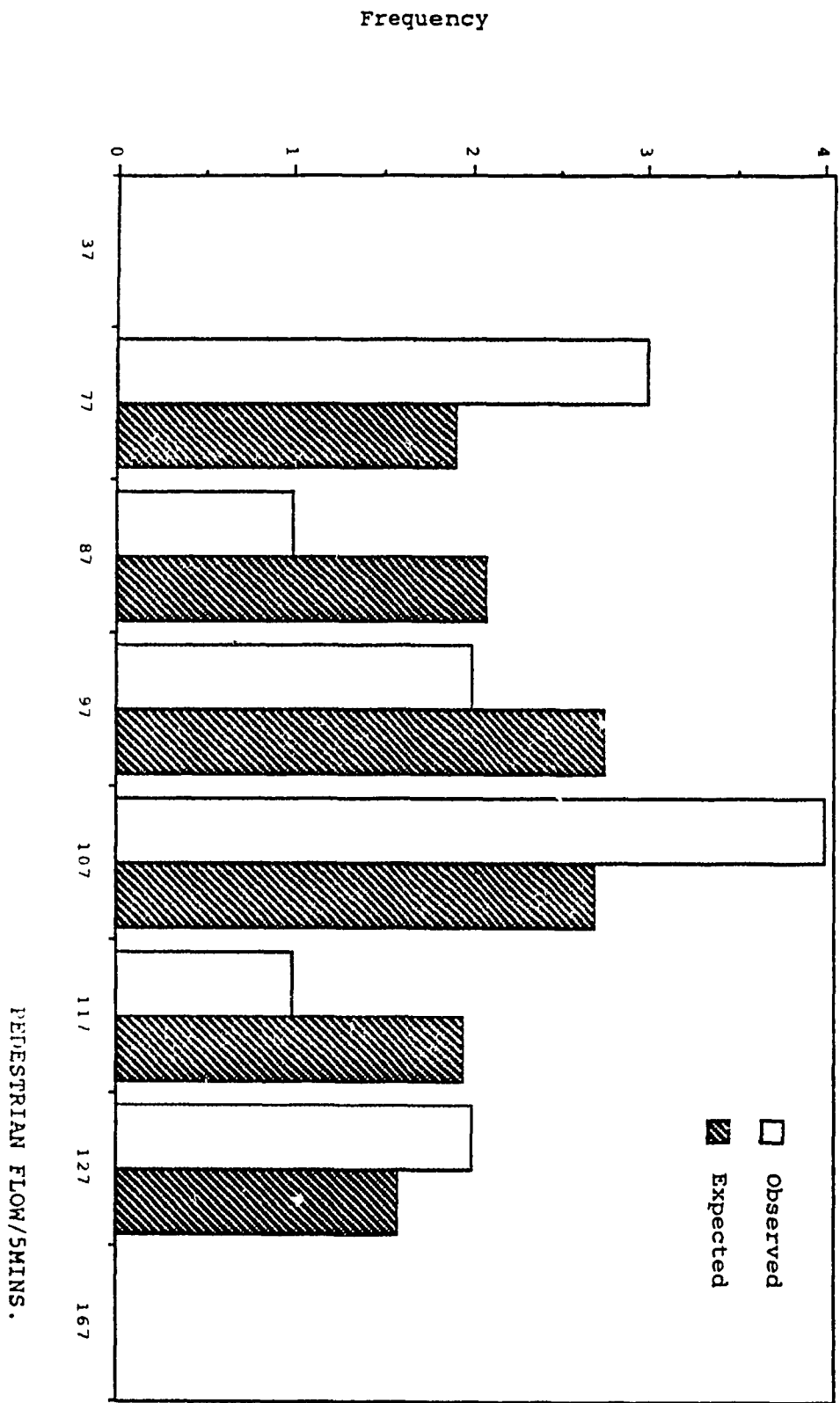


Figure 4.1 Probability Distribution of Five-minute Pedestrian Flows.

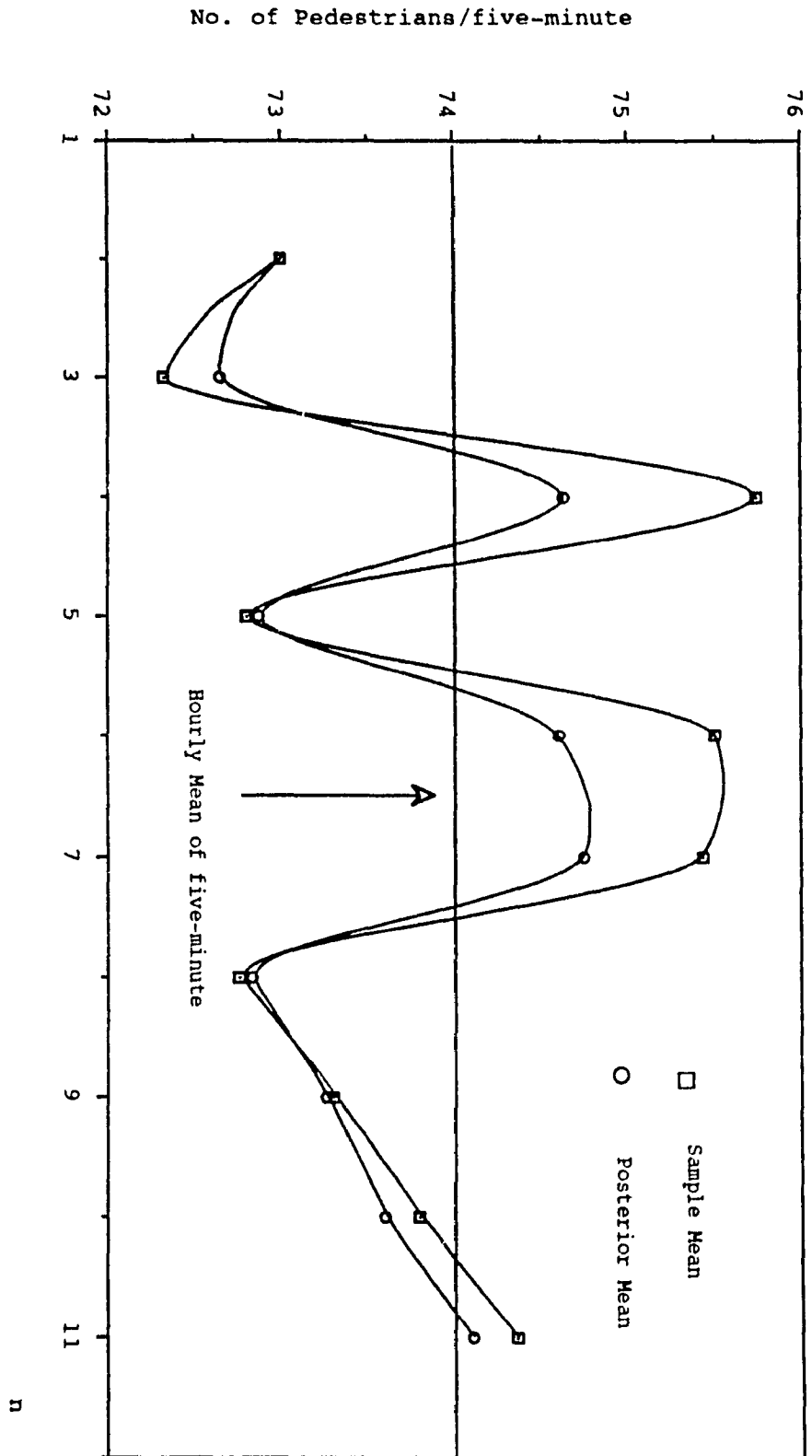


Figure 4.2 Comparison of Posterior and Sample Means.

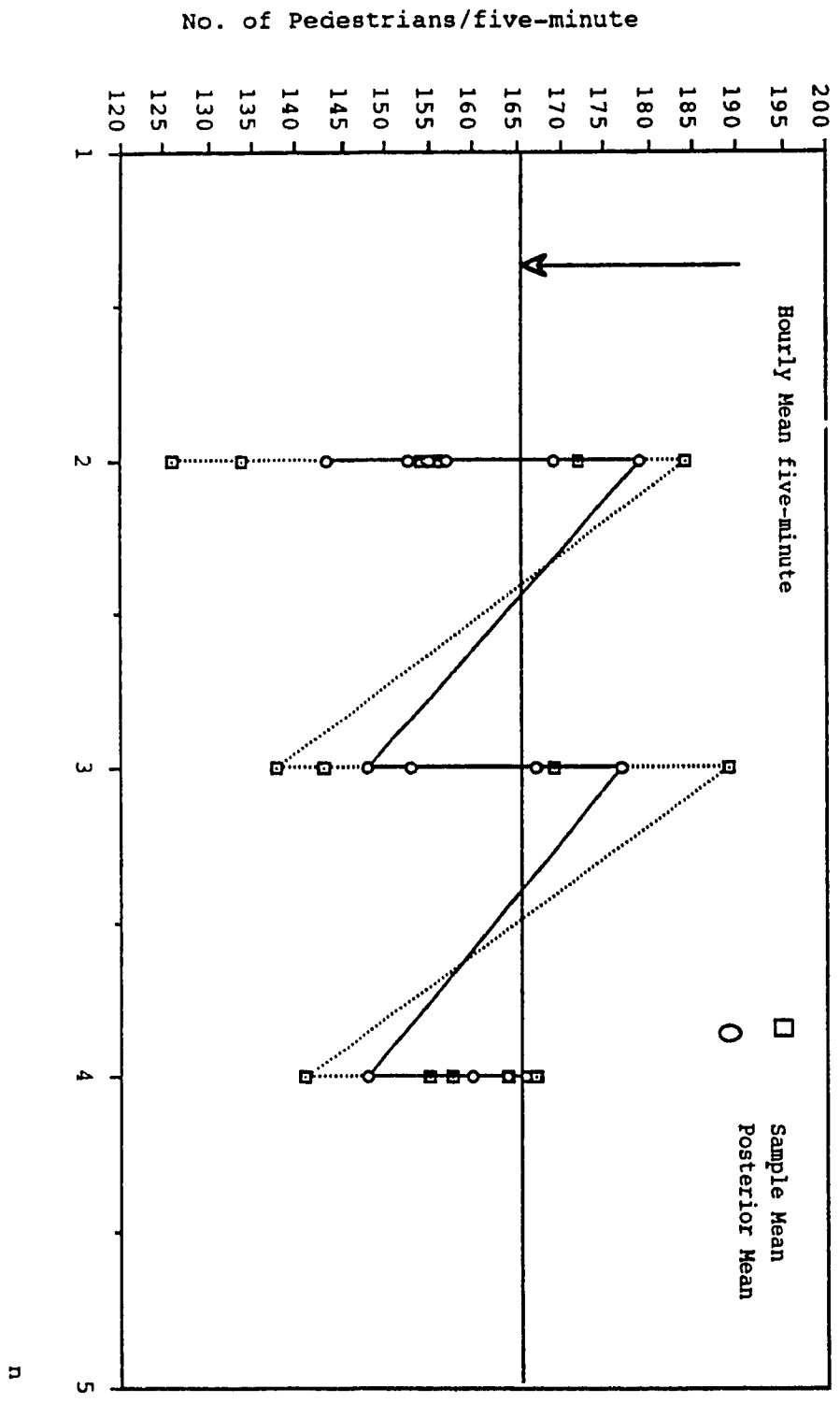


Figure 4.3 Comparison of Different Posterior and Sample Means.

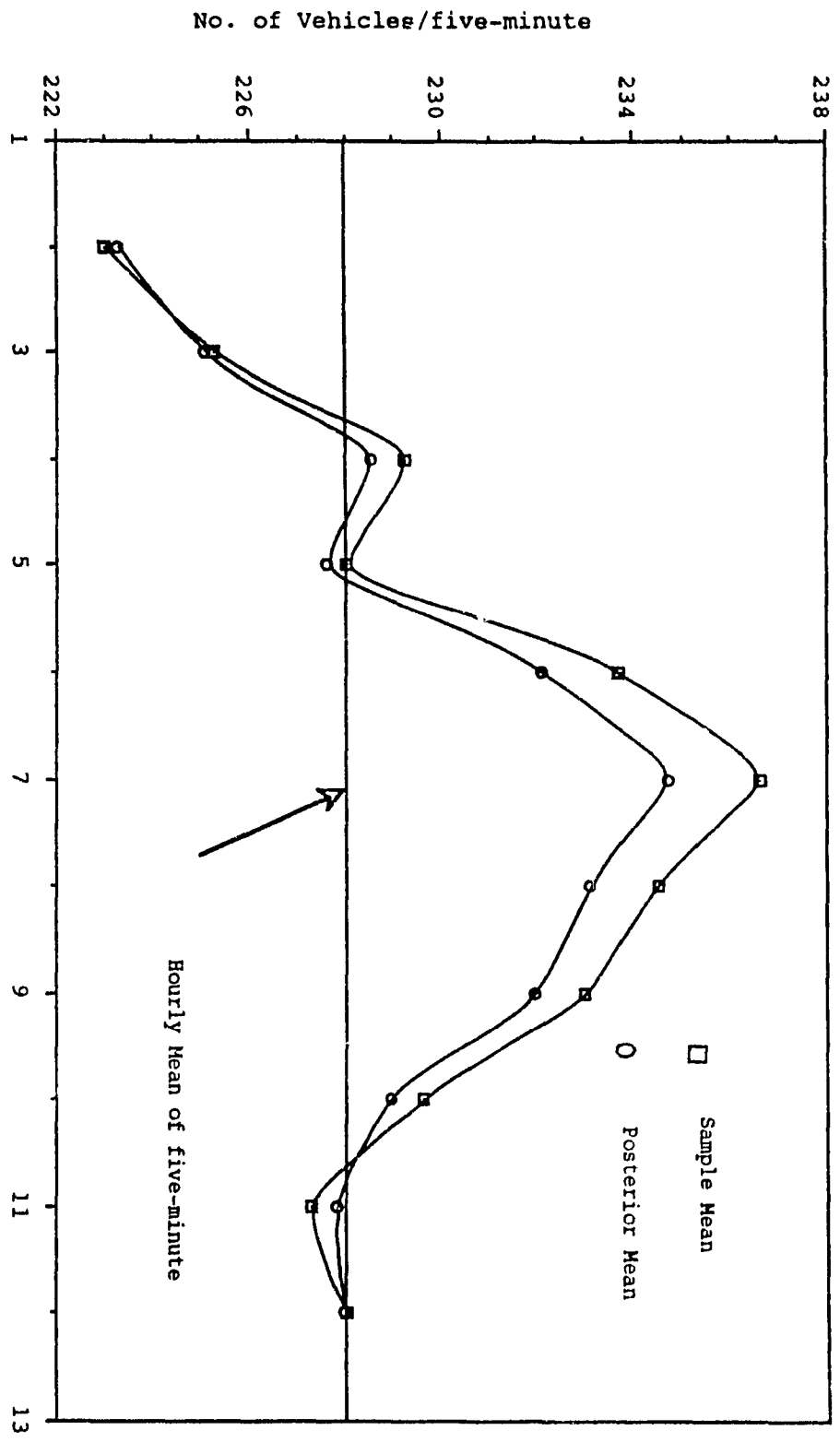


Figure 4.4 Comparison of Posterior and Sample Means.