MEASURING PEDESTRIAN VOLUMES AND CONFLICTS

VOLUME 2: ACCIDENT PREDICTION MODEL

CONTRACT NUMBER: DTFH61-85-C-00079

FHWA-RD-88-037

FINAL REPORT

Prepared for:

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DECEMBER 1987

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/RD-88/037		

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code / 8. Performing Organization Report No.
MEASURING PEDESTRIAN VOLUMES AND CONFLICTS Volume II. Accident Prediction Model	5. December 1987 6. 8.
7. Author(s) S. Davis, D. Robertson, E. King, R. Mingo, J. Washington	
9. Performing Organization Name and Address Analysis Group, Inc. Transportation Engineering Division 500 E. Morehead St., Suite 315 Charlotte, N.C. 28202	10. Work Unit No. (TRAIS) FCP- 11. Contract or Grant No. DTFH61-85-C-00079
12. Sponsoring Agency Name and Address Federal Highway Administration Turner-Fairbank Highway Research Center 6300 Georgetown Pike, HSR-20 McLean, VA 22101	13. Type of Report and Period Covered Final Report June 1985 - August 1987 14. Sponsoring Agency Code

15. Supplementary Notes

COTR: Mr. John Fegan (HSR-20)

16. Abstract

This final report presents the findings, conclusions, and recommendations of the study conducted to model pedestrian/vehicle accidents. A group-type analysis approach for the prediction of pedestrian/vehicle accidents using pedestrian/vehicle conflicts and exposure measures is discussed in terms of statistical methodology, results of approach, and applications of techniques developed. Three- and two-accident group models were developed for two cities. The findings of this study were hampered due to the limited accident data base. Recommendations for further research are offered in order to investigate the use of other variables and the relationship between conflicts and exposure measures.

This volume is second in a series. The others in the series are:

Vol. No.	Title
I	Pedestrian Volume Sampling (Report)
III	Pedestrian Volume Sampling (User's Manual)
IV	Accident Prediction Model (User's Manual)

17. Key Words	18. Distribution Statement
Conflicts, Exposure Measures, Discriminant Analysis	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	101	

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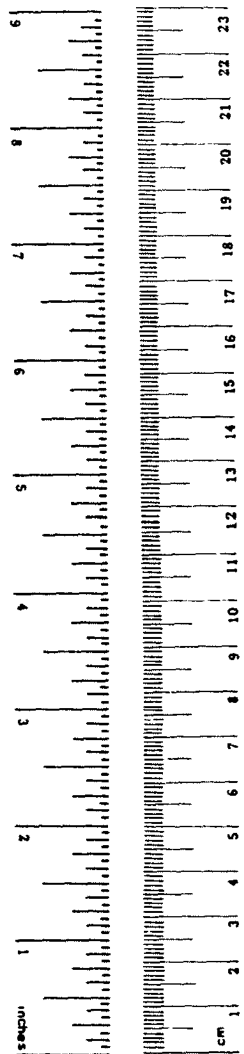
METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
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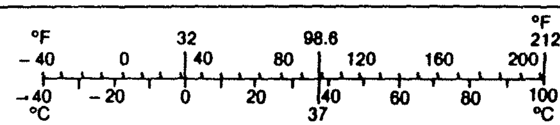

These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

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INTRODUCTION

Background

Traffic conflicts have been used as a measure of the potential for traffic accidents. A traffic conflict occurs when a driver has to take some action, i.e., change in direction, speed, or both, in order to prevent a collision. Several studies have been conducted to determine the relationship of traffic accidents (vehicle/vehicle and vehicle/fixed object) and conflicts and to develop conflict-analysis techniques. However, very little research has been conducted to establish a relationship between pedestrian/vehicle conflicts and accidents. Due to this lack of research, reliable pedestrian/vehicle conflict-analysis techniques have not yet materialized.

In recent studies, the concept of "exposure to risk" has been used to define possible hazards to the pedestrian. Still, relating conflicts to accidents in order to define exposure to risk has not to date produced adequate and sensitive analysis techniques or methods. Along with the lack of research in this area is the difficulty of defining the exact conflict measures that would provide accurate indicators of potential accidents. With well-defined conflict measures, it may be possible to establish a relationship between pedestrian/vehicle conflicts and accidents. With such a relationship, the ability to locate or predict sites where pedestrian accidents might occur would allow actions to be taken to avoid these types of accidents before they occur.

Objectives of the Study

The objectives of this study were to synthesize any existing information on pedestrian/vehicle conflicts, operationally define and determine the relationship of pedestrian conflicts to pedestrian accidents, and develop methods to reliably obtain pedestrian conflict data.

Scope of the Research

This study was concerned with a thorough examination of the various methods and techniques of measuring pedestrian/vehicle conflicts. Since little research existed on the pedestrian/vehicle conflict technique, traffic conflict techniques were identified and evaluated in terms of their potential applications in the definition and development of the pedestrian/vehicle conflicts, data requirements, data collection procedures, cost-effectiveness, uses of data, and other evaluative criteria such as accuracy of data, ease of data collection, and feasibility of methodology. In addition, pedestrian behavior measures and exposure measures were investigated in terms of their usefulness in defining pedestrian/vehicle conflicts and developing accident-potential criteria, respectively.

An extensive literature review was conducted to identify existing methods of measuring vehicle and pedestrian conflicts. The literature review was conducted using annotated searches (TRIS, Compendix-Dialog, Psych Info) and through personal contacts. The literature search concentrated on locating and reviewing studies that involved the use of the following:

- Traffic conflict techniques,
- Pedestrian/vehicle conflicts,
- Risk and exposure, and
- Accident-conflict relationships.

A state-of-the-practice report was prepared detailing procedures, techniques, and conflict definitions. From this report, pedestrian/vehicle conflicts were defined for use in this study. Based upon the conflict definitions, a data collection plan was developed for manual collection of conflict data in Seattle, Washington and Washington, D.C. Twenty-four four-legged intersections in each city with either signal or two-way stop control were randomly selected. Three-year accident histories for these intersections were used. It was assumed that the observed conflict data was representative of the conflicts occurring during the accident history period. The study included all types of pedestrian and vehicles. Along with observed conflict data, pedestrian and vehicle violations and volumes were recorded. These data were used to define and develop the relationship between pedestrian/vehicle conflicts and accidents.

Finally, conclusions were drawn and recommendations were made to further the research efforts in the definition and development of conflict measures and the determination of the pedestrian/vehicle conflict-accident relationship.

STATE-OF-THE-PRACTICE

The occurrence or non-occurrence of traffic accidents is the ultimate measure of safety for any given highway location. Traffic safety research is usually based upon the description, analysis, and classification of the events contributing to an accident. The data used are mainly available from accident reports which have been completed by an investigating officer. In turn, the accident report is based upon statements from persons directly involved, witnesses' statements, physical evidence and conditions at the scene, and inferences of the investigating officer. The persons involved in the accident or witnessing the accident may consciously or unconsciously give biased or incomplete statements and the investigating officer's greatest concern may be in establishing whether or not there has been a violation of the law rather than recording all possible contributing factors. This makes accident records a less-than-satisfactory source of data for evaluating the safety of highway locations. In addition, traffic accidents are a relatively rare occurrence, particularly for any given highway location. Repeated accidents are necessary in order to establish that an accident pattern is related to the features of a specific site and it may take many years to develop an adequate accident experience. Since many factors change with time, it is not certain that these accidents will have occurred under like conditions.

The literature search began with a review of the publication entitled Abstracts of Pedestrian Literature - With Subject and Author Index, organized by the TRB Pedestrian Committee (A3B04), Subcommittee on Publications, January 1985. This document contains abstracts, produced from a search using the Transportation Research Information Service (TRIS), relating to pedestrian research. Using the subject index, abstracts which appeared to be relevant to pedestrian/vehicle conflicts were identified. The author index was used to identify abstracts attributable to researchers known to be currently working or to have formerly worked in the area of pedestrian safety. The abstracts were then used to select articles and reports for further review. It soon became apparent that this process would require the reading of too many publications which were not relevant. Using narrowed subject definitions, two on-line computer searches were performed using the Compendix-Dialog and Psych Info information search systems. The Compendix-Dialog search produced 99 abstracts and the Psych Info search produced 49 abstracts with overlap between the two. It was noted that many of the articles are not relevant to the present project and others appear to be essentially the same paper with revisions to suit the purposes of various conferences and journals.

The pedestrian/vehicle conflict has generally been investigated as part of a more extensive study dealing with a number of traffic conflicts. The concept of traffic conflicts was initiated in the United States in the late 1960's and has since received considerable attention both here and abroad. The development of the Traffic Conflict Technique, for safety evaluation and diagnosis of local safety problems in various countries, has resulted in numerous publications, of differing degrees of interest to this present research. Three Traffic Conflict Techniques Workshops were held in Oslo (1977), Paris (1979), and Leischendam (1982), and an International Calibration Study (1984) was also held in Heidelburg. The papers presented at these meetings reflect the development and use of the Traffic Conflict Technique throughout the world and the proceedings of these meetings have been heavily drawn upon in this literature search, both as a primary reference and as a source of additional references.

Even with this seemingly large base of reference material, the number of relevant articles was relatively small. In order to meet the needs of this project, they were divided into the following categories:

1. Traffic Conflict Techniques
2. Pedestrian/Vehicle Conflict
3. Risk and Exposure
4. Relationship Between Conflicts and Accidents

Traffic Conflict Techniques

Due to the problems associated with the unreliability of accident records and the time required to develop an adequate sample size, attempts have been made to replace accidents with a substitute measure of safety. An early example of this is shown by Forbes (1957) who presents an analysis of "near accident" reports. One concept of a substitute measure was formalized and presented by Perkins and Harris (1968) as the Traffic Conflicts Technique. The conflicts technique, as originally used, was conceived as a method for measuring the accident potential of highway intersections through the analysis of "situations involving one or more vehicles (or other road users) in which an evasive vehicular action is required to avoid a collision." These evasive actions, termed "conflicts," are identified by braking or weaving maneuvers.

Since its introduction the conflicts technique has been used extensively in the United States and various other countries. Although numerous modifications have been proposed, the basic procedures and methods are those originally developed by Perkins and Harris (1967, 1968). A brief description of the terms and procedures currently used in various countries is given in the Malmo Study (Grayson, 1984). While there is no universal agreement as to the definition of a traffic conflict, the general definition used by Perkins and Harris appears to form the basis for various modifications used in different countries. Within the general definition of "evasive vehicular actions required to avoid a collision," specific types of conflicts such as weave conflict, abrupt stop, slow for turning vehicle, etc., have been identified and used. The types of conflicts have varied from country to country and from study to study within a country in order to meet specific site conditions.

The British conflicts technique procedure as reported by Baguley (1982) is based upon the orginal Perkins and Harris methods and conflict definition with the addition of a grading system which assigns each conflict to one of five categories depending upon the severity of the incident. The British method also includes an observer estimate of the time before possible collision when evasive action begins. The French procedure reported by Muhlrad (1982) uses the original method and conflict definition with the addition of a five-point scale for assessing the severity of each conflict. The Finnish procedure (Kumala, 1982) defines conflicts as braking or weaving maneuvers which begin 1.5 seconds before a potential collision and registers them as either serious or mild. The Swedish procedure (Hyden, et al., 1982) also identifies conflicts by the estimated time to collision (TTC) and places them in one of two categories, based upon the speed of the vehicle or vehicles involved. The procedure used in the Netherlands (Horst, 1982) also uses the conflicts technique concept to define conflicts. The Danish procedure (Ludvigsen, 1979) uses the original method and definition with two speed classifications, low and high. Germany (Erke, 1984) uses the original definition and identifies various conflicts in terms of critical maneuvers.

Regardless of any modifications to the original conflicts technique method, as typified by the above examples, all current procedures include a pedestrian/vehicle-type conflict. The conflicts technique procedures are generally used to record all traffic conflicts in order to evaluate the total safety of a location. In this regard the pedestrian/vehicle conflict is one of several being recorded and is given no special attention. It is usually recorded only as a pedestrian conflict with little or no information regarding the nature of the conflict. However, there is a limited number of articles which mention the pedestrian/vehicle conflict, although not always in detail.

Erke (1984) describes the conflicts technique procedure used in the Federal Republic of Germany. A traffic conflict is defined as an observable situation in which two or more road users approach each other in time and space to such an extent that a collsion is imminent if their movements remain unchanged. The occurrence of a traffic conflict is indicated by a critical maneuver of at least one of the involved road users. Critical maneuvers are:

- braking,
- accelerating,
- swerving,
- stopping,
- running, jumping, and
- combinations of these maneuvers.

The degree of severity of a conflict is determined by:

- the distance between the parties involved,
- the speed differential, and
- the strength of the acceleration and deceleration.

Three categories of severity are utilized and may be characterized by:

- Controlled braking and/or swerving or accelerating to prevent a collision.

- Strong braking and/or abrupt swerving or fast acceleration and/or abrupt swerving to avoid a collision.

- Emergency braking and/or swerving in the "last second" or very strong acceleration and/or swerving in the "last second."

Hyden and Linderholm (1984) describe the Swedish conflicts technique procedure which defines a serious conflict as a situation involving two road users where a collision would have occurred within 1.5 seconds if both road users involved had continued with unchanged speeds and directions. The time is calculated from the moment one of the road users starts braking or swerving to avoid the collision. Conflicts are further classified as either low-speed or high-speed situations. Recorded conflicts are used to develop a conversion factor, the ratio between serious conflicts and injury accidents. Conversion factors are given for car-pedestrian and car-bicycle conflicts. However, the procedure collects only enough data to identify the event according to the basic definition and no details regarding the car-pedestrian or the car-bicycle conflict are recorded other than a supplementary written statement regarding the cause of the event.

Guttinger (1977, 1980) uses the Dutch conflicts technique procedure to investigate the safety of pedestrians, especially children, in residential areas. A <u>Serious Conflict</u> is defined as a sudden motor reaction by a party or both parties involved in a traffic situation, towards the other, with a distance of about 1 meter or less between those involved. The two variables, motor reaction and distance, are considered to be important and are used to distinguish a Serious Conflict from other situations, such as:

A Conflict - a sudden motor reaction by a party or both of the parties involved in a traffic situation towards the other with a distance of about 2 meters or more (maximum 20 meters between those involved), or

A Contact - a non-sudden motor reaction by a party or both of the parties in a traffic situation towards the other, with a distance of about 2 meters or more (maximum 20 meters) between those involved.

All three of the above could be called:

An Encounter - a motor reaction by a party or both of the parties involved in a traffic situation towards the other, with a distance of 20 meters or less between those involved.

No further definition of the pedestrian/vehicle conflict is given in either of these articles.

The Swedish conflicts technique procedure has also been used to evaluate a limited number of intersections in Denmark (Ludvigsen, 1980). A conflict is defined as a situation which would have led to an accident if none of the road users involved had taken any evasive action and a serious conflict occurs when the time to collision is below 1.5 seconds. Conversion factors are presented for car-pedestrian and car-bicycle conflicts with two speed classifications. No further definitions of these conflicts are given.

Kulmala (1982) studied the effects of pedestrian refuges in Helsinki using the Finnish conflicts technique. Situations where braking or weaving begins 1.5 seconds or less before a potential collision are defined as conflicts. If braking or weaving is uncontrolled, the conflict is defined as serious. The concept of potential conflict, a situation in which the participants adjust their speeds well before the potential collision, is also introduced. All participants don't behave in an appropriate fashion and the situation nearly ends up in a conflict. Data is presented for pedestrian/vehicle conflicts and pedestrian/vehicle potential conflicts at different pedestrian crossings before and after the installation of pedestrian refuges and for different crossing arrangements. No further description of the pedestrian/vehicle conflict is given.

Muhlrad (1982, 1984) uses the basic definition of a conflict, "an observable situation where the interaction of several road-users (or of a vehicle and the environment) would result in a collision, unless at least one of those involved takes evasive action," which was agreed upon at the First Workshop on Traffic Conflicts, held in Oslo, 1977. For an observer collecting data, a conflict must be recorded:

- If a perceptible evasive action is taken by at least one of the road-users, and if it can be assumed that there would have been a collision without it;

- If a real collision is observed on the location.

An evasive action is described as a discontinuity in the driving, cycling, or walking process, which follows the occurrence of an unpredictable or surprising event. Conflicts are classified on a five-point severity scale which considers both the swiftness and strength of the required evasive action. Based upon the conflict data and accident records, a risk-matrix is established for each observed location. Where applicable, this matrix provides for the pedestrian/vehicle conflict. This paper does not discuss nor define individual conflicts.

Hakkert (1984) notes an Israeli study which defines a conflict as "an event in which one road user causes another road user to change his course of travel in time or space." Both deceleration and acceleration caused by another road user were included as conflicts, as was swerving. This definition differs in that there is no mention of a risk of collision. The investigators felt that this removed much of the subjective evaluation and would increase the sample size of observable conflicts. The basic field form used to record the conflicts provides for the pedestrian/vehicle conflict but gives no further definition of this specific conflict.

Migletz and Glauz (1984) give a generalized definition of a traffic conflict as follows:

> " traffic conflict is a traffic event involving two or more road users, in which one user performs some atypical or unusual action, such as a change in direction or speed, that places another user in jeopardy of a collision unless an evasive maneuver is undertaken."

The road users include both pedestrians and bicyclists. It is further stated that:

> "...it is not necessary that there actually be an evasive maneuver or that there actually be an impending collision. It suffices that the instigating action or maneuver threatens another user with the possibility of a collision and, thereby, places the user in the position of probably taking some maneuver."

Using this basic definition, a set of operational definitions for 14 intersection conflict situations was developed, including a pedestrian/vehicle conflict. The pedestrian/vehicle conflict was further defined as follows:

> "A pedestrian conflict situation occurs when a pedestrian (the instigating road user) crosses in front of a vehicle that has the right-of-way, thus creating a potential collision situation. The vehicle brakes or swerves, then continues through the intersection. Any such crossing on the near side or far side of the intersection is liable to be a conflict situation. However, pedestrian movements on the right and left sides of the intersection are not considered liable to create conflict situations if such movements have the right-of-way, such as during a 'walk' phase."

This definition was developed on the basis of previous research, observations or actual practice, and on evidence in the literature. It excluded conflicts that resulted from vehicle turning movements or other violations of pedestrian right-of-way, and could include situations that did not result in any sort of conflict. Other definitions, including that of Hyden (1982) which utilizes severe conflicts as a time-to-time collision of 1.5 seconds or less, were tested and discarded.

Past studies by Migletz and Glauz were focused on the vehicle/vehicle conflict and this study continued in the same vein with test sites being selected primarily to observe vehicle-vehicle interaction. Intersections containing large amounts of pedestrian traffic were omitted from the study, and conflict studies were conducted during summer months when schools were on vacation.

As indicated by the above studies the majority of the traffic conflict studies performed to date have been primarily concerned with vehicle/vehicle conflicts but have made some provision for recording pedestrian/vehicle conflicts. The basic definition of a traffic conflict used for most studies has included the pedestrian as a road user but with no special emphasis nor additional description of a pedestrian/vehicle conflict. Although Migletz and Glauz (1984) give an operational definition of a pedestrian/vehicle conflict, their study intentionally excluded locations which had high pedestrian volumes. Additionally, in a following article by Glauz and Bauer (1985) which appears to describe the same U.S. technique, the pedestrian/vehicle conflict is completely omitted. However, three articles which define the pedestrian/vehicle conflict in greater detail were reviewed and follow in chronological order.

Pedestrian/Vehicle Conflicts

Robertson, et al., (1977) summarize the research completed in the first phase of a three-phase project. The first phase dealt with the investigation and identification of both operational and safety problems encountered by pedestrians and motorists at urban-type intersections. Their research used the following pedestrian/vehicle conflicts to describe pedestrian activity at an intersection.

Code	Definition
(B)	Backup Movement - Momentary reversal in pedestrian direction of travel in the traffic lane, or hesitation in response to a vehicle in a traffic lane.
(MV)	Moving Vehicle - Through traffic moving through the crosswalk while the pedestrian is in a traffic lane.
(TV)	Turning Vehicle - Pedestrian in the path and within 20 feet of a turning vehicle.
(VH)	Vehicle Hazard - Pedestrian entering a traffic lane when a through vehicle, unrestricted by a traffic control device, is approaching in that lane within one block.
(RVH)	Running Vehicle Hazard Conflict - Running in a traffic lane in response to a VH.
(RTV)	Running Turning Vehicle Conflict - Running in a traffic lane in response to a TV or TV potential.

The selection criteria for the measures are also of interest:

> "First, the behavior must be definable in terms of objective, observable events so that coding is reliable. Secondly, it must occur with sufficient frequency to permit an efficient data collection schedule. Third, the behavior must have construct validity; that is, the candidate behaviors must have an association with intersection safety or flow (assumed or proven)."

Robertson indicates that the conflict measures must be sensitive enough to discriminate between intersections on the basis of accident history, vehicle/pedestrian flow, or some other parameter of interest. They should also be meaningful and believable to the city traffic engineer or other official who will select and evaluate countermeasures.

Cynecki (1980) describes a study whose purpose was to develop a pedestrian conflict technique which could be used to identify hazardous locations and specific operational deficiencies at pedestrian crossings. The study used the following characteristics and attributes to develop the procedure.

> Safety-relatedness - Conflicts must be defined in such a way that they are related to a safety problem or an operational hazard.
>
> Site-relatedness - The conflict definitions which are used must be applicable to the location under investigation.
>
> Reliability - A pedestrian conflict procedure should be valid and have a high statistical correlation with pedestrian accidents.
>
> Repeatability - The procedure must provide consistent results from day to day, location to location, and between observers.
>
> Practicality - The procedure must be easy to use and provide adequate results with a minimum of manpower.

Considering these study characteristics and attributes, thirteen basic types of pedestrian/vehicle conflicts were operationally defined as follows:

Code	Definition
(PW)	Slow or Weave for Walking Pedestrian - This is a conflict which occurs when a pedestrian accesses a a roadway at a normal walking pace and a vehicle weaves or brakes to avoid a collision.
(PR)	Slow or Weave for a Running Pedestrian - This conflict occurs when a pedestrian accesses a roadway while running at right angles to vehicle traffic.
(WF)	Pedestrian Walking/Running in the Roadway with the Flow of Traffic - Vehicle weaves or brakes because of a pedestrian walking or running in the roadway or on the shoulder in the direction of vehicle traffic.

(AF) Pedestrian Walking/Running in the Road Against the Flow of Traffic - Vehicle weaves or brakes because of a pedestrian walking or running in the roadway or on the shoulder opposing the direction of travel.

(PD) Diagonal Pedestrian Crossing - This conflict occurs when a pedestrian crosses the road at an angle other than 90 degrees to the flow of traffic.

(CL) Pedestrian in Center Lane - This conflict designates the presence of a pedestrian in the center left-hand turn lane of a roadway during the commission of a conflict with a vehicle.

(OC) Outside Crosswalk - This conflict occurs outside of a marked crosswalk.

(VR) Right Turning Conflicts - This conflict is the result of a right turning vehicle at an intersection or from a vehicle making a right turn into or out of a driveway.

(VL) Left Turning Conflicts - This conflict is the result of a left turning vehicle at an intersection or from a vehicle making a left turn into or out of a driveway.

(RR) Right-Turn-on-Red conflicts - This conflict occurs when a vehicle initiates a right turn during red signal phase which conflicts with a crossing pedestrian.

(SC) Signal Change - This conflict occurs when the signal for a pedestrian crossing a street turns to red before the pedestrian completes the crossing and a vehicle brakes, weaves, or hesitates in order to avoid a collision.

(PV) Pedestrian Violation - This designates a conflict which occurs as a result of a pedestrian violation of a traffic signal.

(VV) Vehicle Violation - This results from a vehicle violation of a traffic control device.

Three levels of conflict severity, based upon vehicle actions, were used in the study. The use of vehicle actions rather than pedestrian actions was thought to provide for ease of observation and more consistent results. The three levels are defined as:

Minor Conflict - Moving vehicle conflict where a hazardous situation exists, but no actual weaving or braking takes place.

Moderate Conflict - Moving vehicle conflict where braking or weaving is taken by a vehicle in order to avoid a collision with a pedestrian.

Severe Conflict - A near miss accident. Any actual collision witnessed by the observer would be recorded separately on a data form.

Research results showed that both the conflict definitions and severity ratings were easily understood and applied by trained observers.

Zegeer, et al., (1983) report a study performed to determine the operational and safety effects of various pedestrian signalization alternatives. As part of the study, it was necessary to evaluate pedestrian/vehicle conflicts which could be associated with specific objectives of various signalization alternatives. The pedestrian/vehicle conflicts used were as follows:

Code	Definition
(PH)	Pedestrian Hesitation Movement - Pedestrian momentarily reverses his or her direction of travel in the traffic lane or the pedestrian hesitates in response to a vehicle in a traffic lane.
(AC)	Aborted Crossing - Pedestrian steps off curb but later reverses direction back to the curb.
(MV)	Moving Vehicle - Through traffic is moving through the crosswalk within 20 feet (6 m) of a pedestrian in a traffic lane.
(RT)	Right Turn Vehicle Interaction - Pedestrian is in the path and within 20 feet (6 m) of a right-turning vehicle.
(LT)	Left Turn Vehicle Interaction - Pedestrian is in the path and within 20 feet (6 m) of a left-turning vehicle.
(RV)	Running Pedestrian Hazard Conflicts (or Run-Vehicle)- A pedestrian runs in a traffic lane in an effort to avoid a possible collision with a vehicle.

(RC) Run on Clearance - Pedestrian runs at onset of clearance interval in response to the change in the signal indication.

(RTV) Run Turning Vehicle - Pedestrian runs in a traffic lane in response to a turning vehicle or turning vehicle potential.

Some of these pedestrian/vehicle conflict measures are similar to those used by Robertson (1977). Others were included (interactions and aborted crossings) to correspond to specific project objectives.

In addition to the above eight pedestrian/vehicle conflicts, the following three pedestrian violations were also recorded:

- o Pedestrians starting on the clearance interval.
- o Pedestrians starting on the prohibited crossing interval.
- o Pedestrians anticipating the WALK signal, starting just prior to the end of the prohibited crossing interval.

The pedestrian/vehicle conflict definitions used in these three studies were selected to satisfy specific requirements of each study; however, the similarity between the studies is obvious. In addition, these operational definitions show a close relationship with the general traffic conflicts definition of "situations involving one or more vehicles (or other road users) in which an evasive vehicle (or other road user) action is required to avoid a collision."

In view of this past research this study adopted the eight pedestrian/vehicle conflict measures used by Zegeer (1983) with the addition of a Signal Change (SC) conflict used by Cynecki (1980). This study initially consider three levels of conflict (minor, moderate, or severe) as defined by Cynecki (1980). In brief, the nine recommended operational pedestrian/vehicle conflicts were defined as follows:

Code	Definition
(PH)	Pedestrian Hesitation Movement - Pedestrian momentarily reverses his or her direction of travel in the traffic lane or the pedestrian hesitates in response to a vehicle in a traffic lane.
(AC)	Aborted Crossing - Pedestrian steps off curb but later reverses direction back to the curb.

(MV)	Moving Vehicle - Through traffic is moving through the crosswalk within 20 feet (6 m) of pedestrian in a traffic lane.
(RT)	Right Turn Vehicle Interaction - Pedestrian is in the path and within 20 feet (6 m) of a right-turning vehicle.
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(RV)	Running Pedestrian Hazard Conflicts (or Run-Vehicle)- A pedestrian runs in a traffic lane in an effort to avoid a possible collision with a vehicle.
(RC)	Run on Clearance - Pedestrian runs at onset of clearance interval in response to the change in the signal indication.
(RTV)	Run Turning Vehicle - Pedestrian runs in a traffic lane in response to a turning vehicle or turning vehicle potential.
(SC)	Signal Change - Signal changes to red before pedestrian completes his crossing and pedestrian runs or vehicle brakes, weaves, or hesitates.

Risk and Exposure

Another concept to identify hazardous locations is risk and exposure. Cameron, Jacobs, and Wilson have defined this concept as:

RISK = ACCIDENTS/EXPOSURE

All agreed on the basic definition of risk but differed on defining exposure measures. The following were exposure measures defined and used by researchers to date:

- time spent walking,
- number of trips made by walking,
- number of roads crossed,
- distance traveled when walking,
- time spent crossing a road,
- number of pedestrians at a given location, and
- the product of pedestrian and vehicle volumes (P x V) at a given location.

The first three of these exposure measures account for a risk to the total population, not the pedestrian population at a given location. For example: number of trips made by walking would indicate the risk per pedestrian trip, not the risk per pedestrian at a specific location. Distance traveled when walking (road width) and time spent crossing a road could be used in specific locations. However, past studies, i.e., Todd and Walker (1980) and Brog and Kuffner (1981), have only used these exposure measures to define risk of a pedestrian population spanning a large area or city. Therefore, only pedestrian volumes and the P x V product will be further discussed.

The exposure measures of the number of pedestrians and P x V can pertain to specific locations such as intersections and midblock crossings. From these measures, risk at a given location can be determined.

Mackie and Older (1965) used pedestrian counts to determine demographical risk in London. Their risk formula for pedestrian crossing locations used the number of pedestrians as an exposure measure:

Risk = Accidents (2 years) / Pedestrians (12 min. sample).

They were able to give risk values to the individual locations studied. Even though they did not use the number of vehicles as an exposure measure, they did conclude that vehicle volumes were related to risk. They also recognized that as the number of turning vehicles increased, risk increased; as pedestrian density increased, risk decreased.

Cameron (1967) stated that pedestrians were not exposed to risk unless they traveled where vehicles travel. His risk studies in Australia used P x V as an exposure measure. He cited two desirable features of the use of P x V as an exposure measure:

- It is the number of intersecting pedestrian and vehicle paths (can be interpreted as the maximum possible number of conflicts).

- It is consistently summable when partitioned by descriptors of pedestrians and/or vehicles (i.e., total number of pedestrians times number of turning vehicles plus total number of pedestrians times number of through vehicles equals total number of pedestrians times total number of vehicles).

Tobey, et al., (1983) conducted a large-scale field study to identify specific pedestrian trip making characteristics, develop pedestrian exposure measures and to examine these trip making characteristics and exposure measures relative to accident information. 1,357 sites were measured, consisting of 612,395 vehicles and 60,906 pedestrians (20,147 by demographic characteristics and behavior). The pedestrian exposure measure of P X V was used in correlation with various pedestrian and site characteristics and in determining pedestrian accident hazardousness.

In a study conducted by Robertson (1983), curves were constructed relating a hazard index (accident potential) to pedestrian/vehicle characteristics. These characteristics consisted of a pedestrian accident rate, percentage of young and elderly crossing, pedestrians crossing against pedestrian signals, and percentage of pedestrians involved in a pedestrian/vehicle conflict. Accident rates were defined as:

$$\text{ACCIDENT RATE} = \text{ACCIDENT} \times T \ / \ (P \times V)$$

This accident rate was a risk value with (P x V)/T as an exposure measure. T was defined as percentage of turning vehicles. This exposure measure was used on the basis of its higher correlation with accidents when compared against pedestrian volumes, vehicle volumes, and the P x V product.

Robertson recognized through the evaluation of his accident data base that a high incidence of pedestrian accidents were due to turning vehicles. Therefore, the introduction of the percentage of turning vehicles into the denominator of the P x V exposure measure seemed justified. However, this interpretation conflicted with the findings of Mackie and Older who recognized that risk increased as turning vehicle volumes increased. Neither Robertson nor Mackie and Older discussed in depth the relationship between turning vehicle volumes and accidents or risk.

In reviewing the correlation coefficients presented by Robertson, the addition of the percentage of turning vehicles (T) into the P x V measure did not show significant differences. The P x V correlation with accidents was 0.342 while the P x V/T correlation was 0.351. With the small differences in those correlations, the conclusion can be drawn that the P x V/T-accident relationship is not significantly different from the P x V-accident relationship. Therefore, the introduction of T into the P x V exposure measure did not contribute significantly to the exposure-accident relationship.

A study conducted by Knoblauch, et al., (1987) investigated four potential pedestrian accident locations: intersections without marked pedestrian crosswalks; major arterial streets; local streets; and locations lacking sidewalks or pedestrian pathways. The key point of this study in relation to exposure was that these four locations were cited by the use of pedestrian exposure measures.

Even though risk and exposure seem unrelated to conflicts, pedestrian and vehicle volumes are related. Pedestrian/vehicle conflicts cannot occur if pedestrians and vehicles are not present at the same time.

Relationship Between Conflicts and Accidents

If pedestrian/vehicle conflicts are to be used for evaluation purposes in place of injury-accident analysis, they must be properly validated or shown to be an adequate measure of pedestrian safety. Therefore, some relationship between conflicts and accidents must be established. As previously indicated, the pedestrian/vehicle conflict has generally been investigated as part of larger traffic conflicts studies. Numerous attempts have been made to validate these studies and the statistical techniques and results may be of interest to the present study.

An early study by Campbell and King (1970) applied the Perkins and Harris traffic conflicts technique to two rural intersections. The Spearman Rank Correlation Coefficient Test was used to determine the degree of association between conflicts per vehicle and accidents per vehicle. Based upon two years of accident data, no significant association was found at the 0.05 level.

Cooper (1977) recorded traffic conflicts by filming at a single intersection periodically for a period of one year and then compared them to a four-year accident history. The analyses showed that serious conflicts correlated better with accidents than conflict definitions including those of a less serious nature. Of the various definitions evaluated, post-encroachment time had the highest correlation coefficient at approximately 0.50, which was only marginally significant. Similarly, in a second study, correlations between observed conflicts and accidents taking place at freeway entrances were low even when the most severe categories of minimum time to collision were considered. A Spearman Rank Coefficient was also of low order.

Both Lawson (1982) and Cooper (1984) report on a study of five non-signalized intersections in Ottawa, Canada, with a six-year accident history totaling 231 accidents. Post-encroachment time conflicts were recorded and linear correlations between the accident and conflict data sets were examined. The correlations varied considerably for the seven maneuver types observed with r values ranging from -0.03 to +0.92. Due to the limited data base, the results were considered to be inconclusive.

Hyden (1977) describes a three-year project which included both vehicle/pedestrian and vehicle/bicycle conflicts as well as vehicle/vehicle conflicts. The relationship between accidents and conflicts recorded at fifty intersections in Malmo, Sweden, was investigated using stepwise linear regression. The results of the regression analysis indicated that the relationship between the number of observed conflicts per time period and the number of accidents per time period mainly depended upon three road-user-related variables (car/car, car/pedestrian, car/bicycle) and four vehicle-speed-related variables (turning and through vehicles in low-speed nonsignalized intersections, and through vehicles in signalized and high-speed intersections).

Traffic conflict studies at six signal-controlled intersections in Braunschweig and Hanover, Germany, are reported by Zimmerman (1977), Zimolong (1980), and Erke (1984). Pedestrian/vehicle conflicts were recorded as part of the studies although they were not singled out in the data analysis. Conflicts were placed in one of three types: Rear End, Weave, or All for analysis purposes. Simple and multiple correlations produced high correlation coefficients between all three types and accidents on the approach roads. Although statistically significant in most instances, the correlation was not as great between conflicts and accidents recorded within the intersection proper.

Gstalter (1980) abstracts a two-part validation study which observed pedestrian/vehicle conflicts at twelve marked crosswalks at signal-controlled urban intersections and on eight similar road intersections. The results of the study at the signal-controlled crossings showed that the total number of pedestrian accidents compared to observed conflicts produced a correlation coefficient of 0.72 at the 0.01 level. When the conflicts were typed by vehicle movement, either right turn, left turn, or straight through, the highest correlation of 0.87 was obtained for accidents involving straight through vehicles.

In the United States, Baker (1972) reported the results of a three-state study initiated by the Federal Highway Administration and carried out in 1969. A total of 392 intersections were studied before improvements were made and 173 after. Results of a comparison of conflicts and accidents showed a stronger correlation for non-signalized intersections than for signalized intersections, with correlation coefficients of 0.67 and 0.326, respectively, for all conflicts. Both correlations are statistically significant at the 0.05 level.

Zegeer (1978) reports on the use of the conflicts technique in Kentucky, where conflicts and accidents are compared before and after safety improvements at signal-controlled intersections. There was a reduction in both conflicts and accidents after improvements, but no statistical analysis of the results is included in the report.

Glauz (1985) reports on one of the largest and most recent validation studies conducted in the United States. Traffic conflict and accident data were collected at 46 urban intersections located in four cities in the Kansas City metropolitan area. At each intersection three years of accident data (1979 - 1981), four days of conflict counts (from 0700 to 1800 during the summer months of 1982) and one day of volume and turning movement counts were collected. A total of 576 observer days of conflict data, representing nearly 90,000 traffic conflicts, were obtained. Of these, 64,210 conflicts were used in the analysis. The accident data base included 1,292 accidents occurring during the three-year period, 1979-1981. Wet road accidents, single vehicle accidents, nighttime accidents, weekend accidents, and pedestrian accidents were excluded from the analysis. Furthermore, the intersections selected for the study were limited to those with low pedestrian volumes and the study was conducted during summer months when there were not school children pedestrians. The final analysis included only vehicle/vehicle conflicts. Although pedestrian/vehicle conflicts were not included in this investigation, some of the study findings and conclusions reached are of interest to the present study. Of the 1,292 total accidents in the data base, only 319 accidents (approximately 7 per intersection) could be considered conflict related and this number was further diluted by division among 12 conflict types. Some of the twelve conflict types are so rare that they are impractical for operational applications, since they require excessively long periods of time to observe adequate samples. Procedures were developed for estimating the expected rate of intersection accidents and their variance, based upon the observed conflict rate. Computed rates compare favorably with observed rates. The variation in accident/conflict ratios is generally quite large among intersections of the same type as well as those of widely differing characteristics. The study finally concludes that traffic conflicts of certain types are good surrogates of accidents and produce estimates of average accident rates nearly as accurate and precise as those produced from historical accident data.

As previously pointed out, past traffic conflict studies have been mainly concerned with vehicle/vehicle conflicts. Pedestrian/vehicle conflicts have been considered as part of some of the studies but have been excluded from others. Traffic conflict studies have tried to establish a relationship between observed conflicts and accidents. Various studies have used widely-accepted statistical techniques including the Spearman Rank Correlation Test, Principal Component Analysis, Analysis of Variance, Regression and Correlation, and other tests in an effort to show a statistically significant relationship. However, these attempts have met with varying degrees of success. The majority of studies reviewed indicate that while there appears to be a relationship, the correlation between conflicts and accidents is weak for motor vehicles.

The statistical analysis, as well as general study conclusions, are of necessity generally based upon a limited amount of accident and conflict data. The lack of an adequate amount of accident data has been a problem in most past studies. Even though an investigation may begin with a seemingly large data base of total traffic accidents, the number of conflict-related accidents may be much smaller (Glauz, 1985). This problem is compounded when considering only pedestrian/vehicle conflict-related accidents. This literature review did not reveal any currently available accident data base which was completely satisfactory for the present project.

RESEARCH METHODOLOGY

The state-of-the-practice section revealed many studies on conflict techniques, but most were concerned with vehicle/vehicle conflicts and accidents. Some studies considered the pedestrian/vehicle conflict only as a vehicle hindrance while others acknowledged it only in passing. In contrast, this study's primary objective was to relate pedestrian/vehicle conflicts and it therefore followed that 'road users' included both pedestrians and vehicles, not just vehicles.

The pedestrian conflict measures used by Robertson and Zegeer primarily dealt with pedestrian behaviors. Conflict-behavior measures were used in before-and-after-type studies to determine pedestrian behavior changes with different pedestrian signalization alternatives. Therefore, their objectives did not concern the accident prediction problem.

Cynecki, on the other hand, used his pedestrian/vehicle conflict measures as accident-potential indicators. As mentioned previously, all these researchers showed similarities in their conflict measures, but study objectives differed. Cynecki then used his conflicts to determine specific locations within an intersection that presented hazards to the pedestrian. In a sense, Cynecki had an objective similar to this study but on a smaller scale.

Exposure measures have been used to define high risk locations for pedestrians. Exposure was seen by Cameron as a function of (Pedestrian Volume) x (Vehicle Volume). He stated that risk cannot occur where both pedestrian and vehicle volumes do not exist. The same fact holds true for pedestrian/vehicle conflicts and accidents. Robertson used a P x V exposure measure with a turning volume (T). The introduction of turning volumes into a P x V exposure slightly strengthened the accident-exposure measure relationship. Thus, the occurrence of pedestrian/vehicle accidents was examined by correlations and modeling techniques through the use of exposure measures.

Pedestrian and vehicle violations were used in the studies of Cynecki and Zegeer. Cynecki used both violations as conflict measures (violations that produced conflicts). Zegeer only recorded pedestrian violations. Neither study discussed the risk- or accident-violation relationship. In this study, pedestrian and vehicle violations were investigated to better define their relationship to pedestrian/vehicle accidents.

The first approach of this study was to investigate the pedestrian/vehicle conflict-accident relationship for each city. Some of the studies described in the state-of-the-practice used several States or cities to produce their data bases. The purpose of using several States or cities was probably to increase accident variation and total number of accidents since accidents are rare occurrances. However, the use of this type data did not consider possible differences that exist in each State or city between pedestrian and vehicle (driver) behaviors, patterns, and volume magnitudes. This study recognized the differences in these characteristics that may exist in each city. Some cities may be highly urbanized; thus heavier pedestrian and vehicle volumes, violations, and conflicts may exist. In cities that are more rural, volumes, violations, and conflicts may be lower. Either a rural or an urban intersection may produce one accident in three years but under different environments.

The second approach was to consider stratified accident data. The poor correlations found in past research between pedestrian/ vehicle or vehicle/vehicle conflicts and accidents may be attributed to the amount of accident variation. For example, a random sample of 30 intersections was taken from a 3-year accident data base for a given city. This 3-year data base contained intersections with pedestrian accidents ranging from 1 to 15. The maximum amount of accident variation that could be explained thus ranged from 0 to 15 accidents. However, if the sample was truly random, the accident range may have been even smaller. Therefore, the independent variables used in defining accidents would not produce high correlations due to the small variation that existed in the accident data base.

Stratified (grouped) accident data ensures the user of obtaining a broader range of accidents. However, as shown in figure 1, the use of stratified accident data in the analysis of individual accidents versus their respective data eliminates the use of common parametric techniques. The accidents of this study are considered to be grouped ordinal data. Therefore, techniques like Pearson correlations and regression will not produce true results since both require nominal data.

With the recognition of the possible accident data base characteristics, alternative analysis techniques for handling these types of data were considered. Thus, stratifying (grouping) the accident data allowed for pre-examination of applicable analysis techniques.

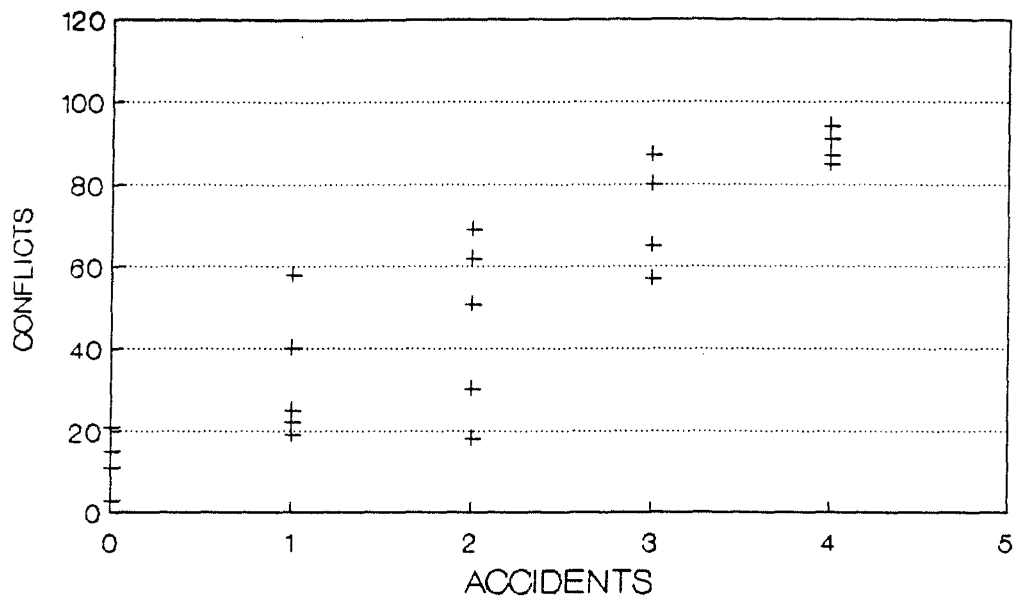

Figure 1. Example of grouped accident data.

DATA COLLECTION

The data collection effort consisted of three parts: (1) a trial field test, (2) the collection of pedestrian/vehicle conflict data, and (3) the collection of accident data. Each part is discussed below in terms of measures of effectiveness, site selection, sampling plan, and data collection procedures.

Trial Field Test

A key component of this project was the selection and definition of conflict measures. This selection was made on the basis of information from the literature review, the results of the trial field test, and input from the Technical Advisory Panel. (See appendix A for a list of panel members.) A trial field test of conflict measures was conducted at three intersections in Washington, D.C. during October 1985. The trial field test was designed to enable the research team to examine a number of conflict measures by viewing video recordings of pedestrians and vehicles at actual intersections. This approach allowed not only the testing of previously used conflict measures, but also permitted the modification of definitions and the application of new conflict measures.

During the trial field test, each of the measures of effectiveness (MOE's) was assessed using the following criteria.

1. The measure must have construct validity, i.e., it must be related to accidents.

2. The measure must occur with sufficient frequency to permit an efficient data collection schedule, i.e., as an indicator of accident potential, it should occur more frequently than accidents themselves.

3. The measure must be clearly definable in terms of objective, observable events and must be trainable for manual observation.

4. The measure must be sensitive enough to discriminate among parameters of interest, e.g., type of location, accident history, and pedestrian/vehicle flow.

5. The measure must be site-related, i.e., applicable to the location being studied. For example, an intersection that would prohibit all right turns would not produce a conflict which is defined by right turning vehicles.

6. The measure must be repeatable and thus provide consistent results from day-to-day, season-to-season, location-to-location, and between observers.

7. The measure must be practical, i.e., meaningful and believable to the user.

8. The measure must be economical, i.e., it must be cost-effective to collect.

Note that the limited amount of trial field test data did not permit a complete assessment of Criteria 1, 2, 4, and 6. These assessments were completed at the conclusion of the field data collection and analysis.

A sample of pedestrians crossing at the three intersections was recorded on video tape during the morning, mid-day, and afternoon peak hours. The key members of the research team viewed the tape together and collectively evaluated the occurrence of the nine conflict measures shown in table 1. Based on this evaluation and input from the Technical Advisory Panel, three of the nine conflict measures were modified and selected as the conflict measures to be used as MOE's in the field data collection effort (table 2).

The conflict measures (table 2) were chosen based on simplicity and practicality. The field observer needs to clearly understand the data he or she is collecting. Removing judgemental parameters, such as severity levels and pedestrian behavior- or action-conflict measures, ensures accurate and uniform data from one observer to the next. Additionally, since the purpose of this study was to develop means of locating hazardous intersections, the broader conflicts, as opposed to the ones in table 1, were more practical for this purpose. More detailed conflict measures are better suited for identifying hazardous points inside an intersection. Finally, if a traffic engineer were to use any technique developed from this study, the conflict measures defined here needed to be straightforward and easily relayed to field observers.

Collection of Pedestrian/Vehicle Conflict Data

The primary goal of this study was to determine if a relationship existed between pedestrian/vehicle conflicts and accidents. This determination was to be made through the analysis of empirical and historical data. The historical data was gathered from city agencies involved with traffic and highway programs. The empirical data was collected on-site by trained observers during a 9-month data collection period.

Table 1. Pedestrian/vehicle conflicts examined.

Code	Definition
(PH)	Pedestrian Hesitation Movement - Pedestrian momentarily reverses his or her direction of travel in the traffic lane or the pedestrian hesitates in response to a vehicle in a traffic lane.
(AC)	Aborted Crossing - Pedestrian steps off curb but later reverses direction back to the curb.
(MV)	Moving Vehicle - Through traffic is moving through the crosswalk within 20 feet (6 m) of a pedestrian in a traffic lane.
(RT)	Right Turn Vehicle Interaction - Pedestrian is in the path and within 20 feet (6 m) of a right-turning vehicle.
(LT)	Left Turn Vehicle Interaction - Pedestrian is in the path and within 20 feet (6 m) of a left-turning vehicle.
(RV)	Running Pedestrian Hazard (or Run-Vehicle) - A pedestrian runs in a traffic lane in an effort to avoid a possible collision with a vehicle.
(RC)	Run on Clearance - Pedestrian runs during clearance interval in response to the change in the signal indication.
(RTV)	Run Turning Vehicle - Pedestrian runs in a traffic lane in response to a turning vehicle or turning vehicle potential.
(SC)	Signal Change - Signal changes to red before pedestrian completes his crossing and pedestrian runs or vehicle brakes, weaves or hesitates.

Table 2. Pedestrian/vehicle conflicts recommended for field data collection.

Code	Definitions
(TV)	Through Vehicle Conflict - Where the projected paths of a through vehicle and a pedestrian cross and either the pedestrian or the vehicle or both must change direction and/or speed to avoid a collision.
(RT)	Right Turn Vehicle Conflict - Where the projected paths of a right turning vehicle and a pedestrian cross and either the pedestrian or the vehicle or both must change direction and/or speed to avoid a collision.
(LT)	Left Turn Vehicle Conflict - Where the projected paths of a left turning vehicle and a pedestrian cross and either the pedestrian or the vehicle or both must change direction and/or speed to avoid a collision.

Site Selection

Data were collected in the cities of Washington, D.C. and Seattle, Washington. Intersections for data collection were selected on the basis of pedestrian accident frequency, type of control (signalized and unsignalized), and intersection configuration (four-way only).

Data for these characteristics were obtained for the total population of intersections from each of the two cities. This population consisted of all intersections with four approach legs, both signalized and unsignalized. Data on pedestrian and traffic volumes were also obtained for these intersections. A sample of intersections was drawn from the population in accordance with the sampling plan described in the next section. The volumes at the sampled intersections were checked to ensure that there were significant amounts of both pedestrian and vehicle activity present. Each site in the sample was visited and checked to ensure that no unique or unusual characteristics existed that could bias test results.

Sampling Plan

A stratified random sample approach was used in this study. The intersections sampled were stratified with respect to type of control and pedestrian accident frequency. Note that several past studies have shown some relationship between pedestrian accidents and volume. Therefore, to avoid a possible duplicate control, the sample was not stratified by pedestrian or vehicle volume.

The procedure to stratify the population was as follows:

1. All intersections in the population were divided into three groups (high, medium, low) on the basis of pedestrian accident frequency where
   High = 3 or more pedestrian accidents in 3 years,
   Medium = 1 to 2 pedestrian accidents in 3 years, and
   Low = 0 pedestrian accidents in 3 years.

2. Each accident group was subdivided into two subgroups with respect to type of control, i.e., signalized or unsignalized.

3. From each of the 6 sub-subgroups, intersections were drawn at random.

The above procedure produced a total of 48 intersections (24 in each city) for inclusion in the study. In Seattle, 13 signalized and 11 unsignalized intersections were selected and in D.C. 16 and 8, respectively. The higher number of signalized intersections chosen was due to low accident frequencies that existed in the nonsignalized intersection group.

Data Collection Procedures

Data were collected manually using field observers provided with push button type counting devices. Since accidents occur in all types of weather, no attempt was made to avoid poor weather conditions during scheduled data collection. The observers were positioned at a vantage point offering a clear view of the crosswalk and approaches. For low- to moderate-volume intersections, one observer was used, while for high-volume intersections, two observers operated as a team.

Each crosswalk and approach was observed for one signal cycle (at signalized intersections) or for a five-minute period (at unsignalized intersections) with conflicts, pedestrian/vehicle counts, and compliance being recorded. Based on this collection scheme, each approach was sampled at least three times during each data collection hour. At high-volume intersections, one observer coded conflicts and noncompliance (pedestrian and vehicle violations used here are defined below) while the other observer counted pedestrians and vehicles. A sample data collection form is shown in appendix B. This procedure was similar to that used in previous studies where intercoder reliability was found to be high. Data were collected at each intersection on weekdays only for six hours per day (7am to 9am, 11am to 1pm, 4pm to 6pm). Each data collection effort required one month to complete (approximately 2 1/2 weeks per city) for three seasons: spring (March, April), summer (July, August), and autumn (October, November). Thus, data were collected at each intersection three times which encompassed the three seasons.

- Pedestrian Violations - starting to cross during the clearance interval, starting on the prohibited crossing interval, anticipating the WALK or green signal and stepping out prematurely, and/or crossing outside the marked crosswalk (if it exists) within 50 feet of the intersection.

- Vehicle Violations - entering during the yellow interval, entering during the red interval, and/or not following special signing or signal constraints such as NO RIGHT TURN ON RED (signal control), running or not stopping completely for a stop sign (stop control).

Training and Quality Control

The training of data collectors was conducted by the Principal Investigator. Training consisted of approximately one hour of classroom type instruction on the purpose of the data collection, the measures to be observed, the method of recording data, and the overall data collection procedure. This was followed by approximately seven hours of field training that consisted of demonstrated data collection techniques, supervised observation and recording, and monitored observation and recording. Data collectors were not permitted to collect field data until an intercoder reliability check with the trainer was 95 percent or greater and recording errors were less than 1 percent.

The Principal Investigator was responsible for quality control and supervised the collection of all data by being present during all data collection activities. In addition, he periodically checked the accuracy of each data collector by duplicating the observing and recording of the measures and comparing his results to that of the data collector. He averaged three such checks on each day of data collection for each data collector.

Collection of Accident Data

Accident data served two purposes in this project. First, it was used as a criterion for site selection, and second, it was used in conjunction with the conflict data to establish the relationship between conflict measures and accidents.

The primary measure was pedestrian accident frequency. A secondary measure was pedestrian accident rate. The calculation of rates required volume data which was either obtained directly from the city, if available, or computed from the counts made during field data collection (6 hours). Data for all police-reported pedestrian accidents at each sampled site for a period of three years prior to the start of data collection and continuing for the duration of data collection were obtained. Data elements of interest included type of accident, (i.e., object struck), time of day, day of week, month of year, and severity.

Accident data were collected for the same sites where conflict data were collected. Data for all police-reported accidents that occurred during the period of interest were obtained. Pedestrian accidents were used directly in the analysis. Based on the high, medium, and low pedestrian accident categories for the intersections sampled, there were approximately 50 to 60 pedestrian accidents in each city's data base.

DATA ANALYSIS

The 3-year accident histories per intersection were obtained for 7-day 24-hour periods. Since the conflict data were collected for weekdays only, the accidents that occurred on weekends were deleted from each intersection data base due to the different pedestrian and vehicle volume magnitudes and distributions that exist between weekdays and weekends. In addition to removing weekend accidents, the accidents that occurred outside of the 6-hour data collection period were initially removed. Seasonal accidents were not considered for deletion from the data base since the data collection effort encompassed spring, summer, and autumn months.

Tables 3 and 4 present 24-hour (7-day), 12-hour (7am to 7pm), and 6-hour (data collection period) accident frequencies for each intersection in both cities. In reviewing the 6-hour accident variation, large groupings of 0- and 1-accident intersections were noted. Thus, to increase the number of accidents and still have the 6-hour conflict data representative of the pedestrian/vehicle accidents, the 12-hour accidents for each intersection were used in the data analysis.

The conflict data included through, right-turn, and left-turn conflicts (defined in the data collection section of this report); pedestrian and vehicle violations; pedestrian volumes; and left-turn, through, and right-turn vehicle volumes. These data were coded on Lotus spreadsheets by hour for each intersection for the three data collection periods. A 1-hour interval was used since many cities collect volume data for 1-hour applications. However, in cases of calculating peak-hour factors, traffic engineers often collect data for 5- or 15-minute intervals, while most traffic signal warrants are based on hourly pedestrian or vehicle volumes.

The importance of defining a time interval lies in the computation of exposure measures. Take the following example of the intersection of 4th and Independence in Washington, D.C. Table 5 presents 1-hour pedestrian and vehicle volumes for the spring data collection period of this study. In the calculation of P x V (pedestrian volume times vehicle volume), the product of the sum for a 6-hour period (1005 x 3406) is 3,423,030 pedestrian-vehicles. The sum of the hourly products (114 x 684 + ... + 100 x 634) is 573,159 pedestrian-vehicles. Since the P x V product defines the maximum possible number of potential conflict occurrences, the sum of the products is more accurate in defining these potential conflict occurrences. (It is also important to note that the count interval used should be consistent.) Therefore, using a smaller count interval better defines the actual conflict potential.

Table 3. Accident frequencies for Washington, D.C.

Intersection	Accidents 24-hr.	12-hr.	6-hr.
14th & K, NW	10	8	7
8th & H, NE	10	5	5
14th & P, NW	7	4	4
Benning & Minnesota, NE	6	3	3
4th & Independence, SW	5	4	2
7th & Independence, SW	2	2	2
17th & H, NW	3	2	2
3rd & K, SE	3	1	1
8th & E, SE	2	1	1
17th & Pennsylvania, NW	1	1	1
Connecticut & Morrison, NW	1	1	1
12th & U, NW	3	1	1
Wisconsin & Warren, NW	2	1	1
15th & H, NW	1	1	1
18th & Massachusetts, NW	1	0	0
4th & E, SE	1	0	0
Garrison & Wisconsin, NW	0	0	0
3rd & C, SE	0	0	0
Ellicot & Connecticut, NW	0	0	0
1st & D, SE	0	0	0
13th & G, NW	0	0	0
17th & Constitution, NW	0	0	0
6th & Maryland, SW	0	0	0
5th & G, NW	0	0	0

In theory, the count interval should be at every second that a pedestrian and vehicle occupy a space at a given location. This, of course, is impractical for use in engineering applications. The use of 5-, 10-, 15-, and 20-minute count intervals for computing exposure would produce more accurate figures than in using 1-hour counts. However, as mentioned earlier, most volume data are collected based on hourly counts, thus the use of hourly volume counts was considered more practical.

From the state-of-the-practice section of this report, two computed exposure measures were of interest for use in the analysis: (1) the pedestrian and vehicle volume product and (2) the pedestrian and vehicle volume product divided by percentage turns. These exposure measures were computed based on the sum of 1-hour products. These two measures, along with the additional data collected in this study, are presented in appendix C.

The two cities of Washington, D.C. and Seattle, WA were analyzed separately due to the differences in their accident

Table 4. Accident frequencies for Seattle, Washington.

Intersection	Accidents 24-hr.	12-hr.	6-hr.
NE University & 45th	7	4	3
S 1st & Lander	5	5	4
N 5th & Broad	5	1	1
E 18th & E Cherry	3	2	2
12th & E Spring	3	2	1
21st & E Cherry	3	1	1
Broadway & E Pike	2	2	2
9th & E Madison	2	2	1
S Rainier & Cloverdale	2	1	1
S 14th & Cloverdale	2	1	1
Fremont & N 35th	1	1	1
SW 26th & Roxbury	1	1	1
NE Brooklyn & 47th	1	1	1
S 12th & S King	1	1	1
NW 8th & Market	3	2	0
Western & Virginia	1	1	0
N Coaliss & 45th	2	1	0
W 2nd & Roy	1	0	0
W 34th & W Dravus	1	0	0
Western & E Spring	0	0	0
8th & NW 85th	0	0	0
3rd & NW 85th	0	0	0
NE Brooklyn & 40th	0	0	0
Olive Way & E Boren	0	0	0

Table 5. Hourly pedestrian and vehicle volumes for 4th and Independence.

	Pedestrian Volume	Vehicle Volume
	114	684
	73	429
	278	506
	202	406
	238	747
	100	634
Total	1,005	3,406

frequencies, conflict occurrences, and pedestrian and vehicle volumes. In a comparison between the two cities' databases, the intersections sampled in Seattle had fewer accidents and conflict events and lower volumes.

The analysis effort was directed towards group modeling since correlating the stratified accident data with the collected data would not have produced usable results. Pearson moment correlations require nominal data which excludes the ordinal accident data. Spearman rank correlations would cause numerous ties between ranks among the accident data which would hamper the correlation coefficients.

Discriminate analysis was chosen since this analysis technique models groups by use of discriminating variables. The groups that were used in this analysis were the three accident groups stated in the data collection section of this report. As for the discriminating variables, past research had to be investigated to aid in locating potential variables to be used in the modeling effort.

From the state-of-the-practice section of this report, conflicts have been used in defining potential pedestrian and vehicle accident sites. Exposure measures, such as pedestrian and vehicle volumes and distance or time traveled, have been used to define risk. Therefore, the variables collected or computed in this study for use in the modeling effort were number of lanes, pedestrian/vehicle conflicts, pedestrian and vehicle volumes, and the products of P x V and P x V/%T. In addition to these variables, type of control and vehicle-pedestrian violations were used.

In the following discussion of the modeling effort, Washington, D.C. data will be detailed in terms of the procedures used in discriminate analysis. The Seattle modeling effort will follow that discussion. For a discussion on discriminate analysis refer to appendix D.

Since both pedestrians and vehicles have to exist at the same time at a given location in order for a conflict or accident to occur, these two variables were entered into the modeling effort first. From the discriminate analysis procedure, table 6 was generated. The column labeled "Number" is the number of observations assigned to the expected group number based on the equations derived in the discriminate analysis process. Using group 1 (zero-accident intersections) for an example, a total of 10 intersections belong to this group. From the equations based on pedestrian and vehicle volumes for each group, seven intersections fell into group 1 while one intersection fell into group 2 and two into group 3. Thus for these equations based on pedestrian and vehicle volumes, 70 percent of the intersections were

Table 6. Classification matrix based on the variables of pedestrian and vehicle volumes for Washington, D.C.

Group*	Expected Group	Number	% Correct
1	1	7	70
	2	1	
	3	2	
	Total	10	
2	1	5	22
	2	2	
	3	2	
	Total	9	
3	1	1	80
	2	0	
	3	4	
	Total	5	
	Overall (all 3 groups)		62.5

*Group 1: 0 accident intersections
Group 2: 1 and 2 accident intersections
Group 3: 3 or more accident intersections

placed into their appropriate group (group 1). Overall, 62.5 percent (15 correct/24 total) of the intersections were placed into their correct groups.

It was apparent that pedestrian and vehicle volumes explained a substantial amount of variation in groups 1 and 3. However, these two variables did not aid in predicting group 2 accidents. Another variable had to be selected that may help explain group 2's variation. The next variable entered was conflicts.

For group 3 in table 7, the accuracy of the prediction reduced from 80 to 60 percent with the addition of conflicts into the model. This type of occurrence is due to the negative effect of conflicts in group 3. When variables are added into the models (group 1, 2, and 3), the first inclination is that these variables will produce a positive effect, thus increasing the group model accuracy. However, this is not always the case since some group variable values may be found in other groups' variable values. Therefore, one or two intersections in group 3 were best defined (by conflicts) to reside in groups 1 and 2 due to these intersections' possible conflict similarities associated with the conflict counts of groups 1 and 2. Refer to appendix D for a discussion on group overlap.

The classification matrix for the variables of conflicts and pedestrian and vehicle volumes is shown in table 7. The addition of conflicts into the model aided both groups 1 and 2. The model, overall, improved its predictive accuracy from 62.5 percent to 70.8 percent.

Table 7. Classification matrix based on the variables of conflicts and pedestrian and vehicle volumes for Washington, D.C.

Group	Expanded Group	Number	% Correct
	1	9	
1	2	0	90
	3	1	
	1	3	
2	2	5	56
	3	1	
	1	1	
3	2	1	60
	3	3	

The process of adding, deleting, and replacing variables continued until the best model was found. (The models that did not work or improve the existing model are presented in appendix G). The final model classifications and equations are shown in tables 8 and 9. By introducing type of control and pedestrian violations, the model's accuracy improved to 83 percent. Group 1 was less accurate when compared to the previous model. However, the research team felt that a model should be conservative and predict accidents where they may not exist rather than fail to predict where they did occur. Thus, this model was chosen to be the best predictor of accidents. Refer to appendix D for examples and equation interpretations.

Note the following comparison between discriminate analysis and regression analysis assumptions.

- o Unlike regression, the number of variables compared to sample size in discriminate analysis does not have to be a 1 to 3 ratio.

Table 8. Classification matrix based on the variables of conflicts, pedestrian and vehicle volumes, type of control, and pedestrian violations for Washington, D.C.

Group	Expected Group	Number	% Correct
	1	6	
1	2	2	60
	3	2	
	1	0	
2	2	9	100
	3	0	
	1	0	
3	2	0	100
	3	5	

Table 9. Equations for the model based on conflicts, pedestrian and vehicle volumes, type of control, and pedestrian violations for Washington, D.C.

group 1: $G1 = -0.0829C + 0.0041P + 0.0026V + 3.4671S + 0.0222Vp - 3.3074$

group 2: $G2 = -0.0099C + 0.0006P + 0.0016V - 1.0553S + 0.0127Vp - 1.5951$

group 3: $G3 = -0.0989C + 0.0045P + 0.0037V + 4.8675S + 0.0254Vp - 6.1205$

where:
C = conflict
P = pedestrian volume
V = vehicle volume
S = type of control (1-signal, 0-stop)
Vp = pedestrian violations

- Intercorrelation between discriminating variables may exist in the model.
- The evaluation of the discriminate model's accuracy is not based on correlations or explained variations but on the model's ability to predict the correct group that the initial groups belong in.

From the analysis procedure, Seattle data produced the best groupings using pedestrian and vehicle volumes, conflicts, and number of lanes. Refer to tables 10 and 11. Other trial models are presented in appendix H. The model's overall accuracy was 75 percent.

Table 10. Classification matrix based on the variables of conflicts, number of lanes, and pedestrian and vehicle volumes for Seattle, WA.

Group	Expected Group	Number	% Correct
	1	6	
1	2	1	86
	3	0	
	1	3	
2	2	11	73
	3	1	
	1	0	
3	2	1	50
	3	1	

Table 11. Equations for the model based on conflicts, number of lanes, and pedestrian and vehicle volumes for Seattle, WA.

group 1: $G1 = 0.0943C + 0.0023P - 0.0047V + 1.6625L - 9.4869$

group 2: $G2 = 0.0533C + 0.0058P - 0.0065V + 2.0950L - 14.0488$

group 3: $G3 = 0.0675C + 0.0155P - 0.0058V + 2.4968L - 27.3187$

where: L = number of lanes

Since group 3 for both Washington, D.C. and Seattle had a small number of observations, the reliability of this group model's accuracy was questionable. Thus, the next step in the modeling process was to investigate the use of two groups: group 1 - zero accidents, group 2 - one or more accidents.

The first inclination to the two-group approach was to use the variables that best defined the three groups of accidents. For Washington, D.C. this was not the case. As shown in table

12, the models predicted the correct group approximately 60 percent of the time (overall, for both groups, 62.5 percent). These results indicated that some variables could not distinguish between the two groups even though they could distinguish among three groups. Therefore, the process of adding, deleting, and replacing variables into the model proceeded until the best model prevailed.

Table 12. Classification matrix based on the variables of conflicts, pedestrian and vehicle volumes, type of control, and pedestrian violations for Washington, D.C.

Group*	Expected Group	Number	% Correct
1	1	6	60
	2	4	
2	1	5	64
	2	9	

* Group 1: 0 accident intersections
Group 2: 1 or more accident intersections

The best model in terms of overall accuracy (75 percent) used the variables of pedestrian and vehicle volumes, conflicts, type of control, and number of lanes. Tables 13 and 14 show the classification matrix and group equations.

Table 13. Classification matrix based on the variables of pedestrian and vehicle volume, conflicts, type of control, and number of lanes for Washington, D.C.

Group	Expected Group	Number	% Correct
1	1	8	80
	2	2	
2	1	4	71
	2	10	

In Seattle, the first inclination prevailed. The 2-group model's overall accuracy was 83 percent. The matrix and equations are shown in tables 15 and 16.

Additional trials using two groups for Washington, D.C. and Seattle are presented in appendices I and J, respectively.

Table 14. Equations for the model based on pedestrian and vehicle volume, conflicts, type of control, and number of lanes for Washington, D.C.

group 1: $G1 = 0.0139C - 0.0019P - 0.0029V + 2.0773S + 0.8544L - 4.7114$

group 2: $G2 = 0.0475C - 0.0045P - 0.0038V + 0.6226S + 1.1048L - 6.9865$

Table 15. Classification matrix based on the variables of pedestrian and vehicle volumes, conflicts, and number of lanes for Seattle, WA.

Group	Expected Group	Number	% Correct
1	1	6	86
	2	1	
2	1	3	82
	2	14	

Table 16. Equations for the model based on pedestrian and vehicle volume, conflicts, and number of lanes for Seattle, WA.

group 1: $G1 = 0.0934C - 0.0013P - 0.0052V + 1.5888L - 8.5028$

group 2: $G2 = 0.0505C + 0.0024P - 0.0070V + 2.0441L - 13.4090$

All models developed in this study were based on three-year accident histories and on the assumption that the pedestrian-vehicle volumes and conflicts as well as the intersection geometrics remained relatively constant over the past three years. The models will predict the number of accidents (accident groups) that would be expected to occur over the next three years assuming that variables other than those in the models remain relatively constant. With this in mind, the user must have the means of estimating future volumes and conditions.

Future pedestrian and vehicle volumes may be forecasted by using growth factors for the intersection(s) under investigation. With these adjusted volumes, pedestrian/vehicle conflicts and violations can be predicted.

Figure 2 shows the scatter diagram of P x V versus conflicts from the Washington, D.C. data base. The Spearman Rank correlation coefficient for these two variables was 0.9374 ($p = 0.0001$). On the basis of this correlation, the P x V exposure can be used to predict conflicts. Existing rates of conflicts/P x V can be associated with the generated P x V exposure. Thus, the future conflict events would be estimated for use in the accident prediction model. For example, an intersection presently has a pedestrian volume of 200, a vehicle volume of 1,500, and a conflict count of 50. Based on 3-year generation rates, this intersection will have 300 pedestrians and 2,000 vehicles. Thus, the conflicts that would occur in the third year would be

$$\frac{50}{200 \times 1500} (300 \times 2000) = 100 \text{ conflicts.}$$

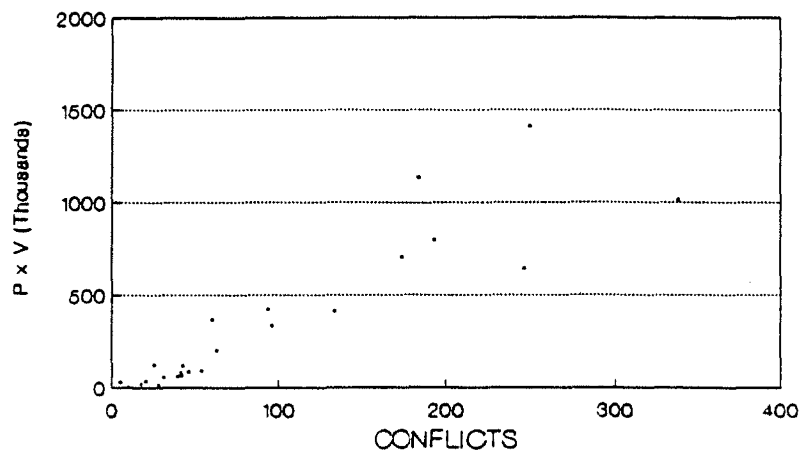

Figure 2. Scatter diagram of P x V versus conflicts for Washington, D.C.

In addition to estimating pedestrian/vehicle conflicts, pedestrian and vehicle violations can be forecasted by pedestrian and vehicle volumes, respectively. A correlation coefficient of 0.7739 ($p = 0.0005$) was found between pedestrian violations and volumes and 0.6833 ($p = 0.0014$) between vehicle violations and volumes. Also, the conflict measures were correlated with pedestrian and vehicle violations, 0.7104 ($p = 0.0010$) and 0.8280 ($p = 0.0002$), respectively. All of these correlation results indicated an increase in volumes produces higher violation occurrences which in turn produced more conflict events. However, in this study, conflicts were not collected in terms of "conflicts caused by violations." Thus, high violation occurrences associated with high conflict events was stated only because of the high correlations between these variables. Nevertheless, rates can be computed to estimate future violation occurrences for both pedestrians and vehicles.

In the investigation of the Seattle data base, the conflict-P x V/%T relationship produced the best Spearman correlation, 0.5328 ($p = 0.0103$). The conflict-P x V correlation was slightly lower at 0.4828 ($p = 0.0194$). A comparison between the P x V/%T and P x V-conflict relationship in terms of explained variance did not reveal any significant differences. P x V/%T explained 0.2330 (23.20%) of the conflict variances while P x V explained 0.2839 (28.39%). The gain of approximately 0.05 (5%) explained conflict-variance is of little statistical value. Similar findings were observed in the Robertson (1983) study. Thus, the addition of percent turning vehicles randomly increased the P x V/%T-conflict relationship which shows that the P x V-conflict relationship was the more true relationship.

Seattle's P x V-conflict correlation was not as high as found in Washington, D.C. In studying this scatter diagram (figure 3), evidence of missing data points was observed. All but two data points were concentrated in the lower left region of the scatter plot. The correlation was hampered due to this concentrated data since the correlation was weighted towards defining the lower concentration of data points. With this particular data base, the conflict rate approach is not recommended. However, if additional data added points to the data base that filled this gap, a better correlation would result.

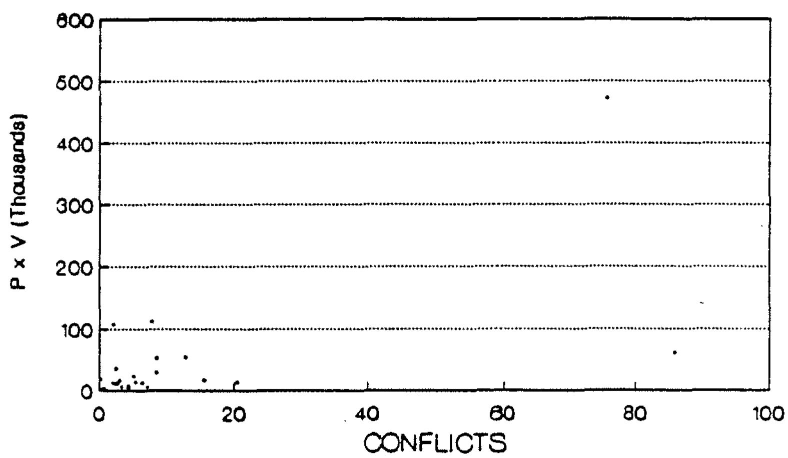

Figure 3. Scatter diagram of P x V versus conflicts for Seattle, WA.

For estimating violations, both pedestrian and vehicle volumes produced the best correlations. Pedestrian volume and pedestrian violations had a correlation of 0.7172 ($p = 0.0009$) while 0.7113 ($p = 0.0010$) was produced for vehicle volume and violations. Even though the Seattle model did not use either violation, these correlations were presented to further demonstrate the relationship between pedestrian-vehicle volumes and violations.

In summary, these correlations were presented to provide a rationale for using rates to estimate future parameters that could not have been produced through present-day techniques. The relationships developed from the Washington and Seattle data are only valid in these two cities, respectively. Correlations and rates would have to be generated for each model developed for a given city since the models are location-specific.

APPLICATION OF THE PEDESTRIAN/VEHICLE ACCIDENT PREDICTION MODEL

The pedestrian/vehicle accident model developed in this study provides a methodology of predicting potential pedestrian/vehicle accidents at intersections. The model was designed for use at four-legged, signalized, and two-way stop-control intersections. However, this methodology may be applied to other types of locations, such as three-legged intersections, four-way stop-control intersections and/or mid-block locations. Also, the methodology developed in this study is location-specific, i.e., the models developed here apply only to the two cities in which the data were collected. Even though the model development is location- specific, the methodology may be utilized by other municipalities. Therefore, each municipality would have to develop their own models based on their unique data bases.

The model predicts accidents (accident groups) for given points in time for an intersection. For example, a model using three-year accident histories in its development would predict accidents that would be expected to occur over the next three years. The primary user of the model would be a municipality traffic engineer interested in identifying and analyzing hazardous locations. The practical applications or uses of this model are (1) to evaluate implemented countermeasures, and (2) prioritize hazardous locations.

As an evaluative tool, these predictive models can be used to determine the effectiveness/benefits of different countermeasures in a before-and-after type analysis. For the priority applications, the model could aid the engineer in ranking hazardous locations and thus, aid in the decision of which locations need immediate treatment and which ones could be treated at a later time.

CONCLUSIONS AND RECOMMENDATIONS

The modeling effort produced significant results in predicting potential pedestrian/vehicle accident or non-accident intersections. By the use of the discriminate analysis modeling technique, 3- and 2-group models were developed for the cities of Washington, D.C. and Seattle, WA. The 3-group models consisted of these groups: group 1 - zero accident intersections, group 2 - one and two accident intersections, and group 3 - three or more accident intersections. In Washington, D.C., the variables of pedestrian and vehicle volumes, conflicts, type of control, and pedestrian violations best explained the 3 accident groups with a model accuracy of 83 percent. For the Seattle 3-group model, pedestrian and vehicle volumes, conflicts, and number of lanes best explained the accident groups with a model accuracy of 75 percent.

Due to the limited amount of accident data for group 3 (three or more accident intersections; Washington, D.C. had 5 intersections and Seattle, WA had 2 intersections), the models from both cities were reduced to two groups: group 1 - zero accident intersections, group 2 - one or more accident intersections. Basically, the two-group model predicts an intersection's potential for having or not having an accident. For the applications of evaluating countermeasures and prioritizing hazardous sites, the two-group model is of little value since it cannot distinguish among accident frequencies. The 3- and 2-group models are presented in table 17.

In both cities of Washington, D.C. and Seattle, it became evident that pedestrian and vehicle volumes and pedestrian/vehicle conflicts were the primary variables in defining pedestrian/vehicle accident occurrences. In contrast, the pedestrian-vehicle volume product (P x V) or P x V divided by the percentage of turning vehicle volume (P x V/%T) measures which represent both pedestrian and vehicle volumes and (potential) conflicts, did not perform well in the modeling analysis. These two exposure measures hamper, in one aspect, the true value of their product. There may exist 20 pedestrian and 20 vehicles at a given location in a given time frame. This P x V product is 400 pedestrian-vehicles which indicates 400 potential conflict events. There may exist a location with 2 pedestrians and 200 vehicles. Again this P x V product indicates a 400 conflict potential, but not in the same sense. Thus, treating pedestrian-vehicle volumes and conflicts as single variables did not distort their value or relationship. The pedestrian and vehicle volumes indicated the presence of activity with respective magnitudes, while the conflicts defined their actual accident potential interaction (not their maximum conflict potential).

The use of the type of traffic control variable was also an indicator of pedestrian and vehicle activity. A stop control intersection usually indicates low pedestrian-vehicle volumes and activity. A signalized intersection usually indicates either or both high-pedestrian and high-vehicle activity. Therefore, the use of this variable may be of some importance when defining accidents.

The Washington, D.C. 3- and 2-group models used type of traffic control to define accident groupings while the Seattle model did not. Due to the pedestrian and vehicle volume differences between the two cities, the use of traffic control may have been more representative of the potential pedestrian/vehicle interaction that occurred in Washington, D.C. In reviewing both cities' data sets, the stop-control intersections of Washington, D.C. had low pedestrian volumes and moderate vehicle volumes when compared to the signalized intersections. In Seattle, however, several stop-control intersections had high pedestrian volumes and moderate vehicle volumes when compared to the signalized intersections. Thus, type of control was not distinctive when compared to pedestrian and vehicle volumes.

Both Seattle (3- and 2-group) models and the Washington, D.C. (2-group) model contained the variable, number of lanes. The number of lanes on the intersection approaches gives an indication of the time or distance that the pedestrian must traverse or the number of conflict locations (the number of conflict locations being the number of places where the pedestrian and vehicle can interact). These places are in the travel lanes. (Note: Accidents that occurred off the roadway were not part of the accident data base in this study). In both cities, the occurrence of accidents increased as the number of lanes increased.

Differences in pedestrian behaviors between the two cities were apparent when comparing pedestrian violations. Pedestrian violations were found to be indicators of accident groupings in Washington, D.C. In this city, numerous pedestrian violations occurred. In Seattle, the opposite was true. Pedestrian violations in Seattle may be of little importance when compared to the pedestrian and vehicle volumes that existed. A pedestrian may walk against the pedestrian signal in Seattle, but a car may not be near the area. However, Washington, D.C. pedestrian and vehicle volumes were greater in magnitude. Thus, a violation by a pedestrian may have been more meaningful in Washington, D.C. in defining accidents.

Lastly, vehicle violations were not useful in defining accident groupings. Vehicle violations of running a red signal or stopping in the cross-walk would not impose on a pedestrian if

Table 17. 3- and 2-group models for both cities of Washington, D.C. and Seattle, WA.

<u>Washington, D.C. 3-group model</u>

group 1: $G1 = -0.0829C + 0.0041P + 0.0026V + 3.4671S + 0.0222V_p - 3.3074$

group 2: $G2 = -0.0099C + 0.0006P + 0.0016V - 1.0553S + 0.0127V_p - 1.5951$

group 3: $G3 = -0.0989C + 0.0045P + 0.0037V + 4.8675S + 0.0254V_p - 6.1205$

<u>Seattle, WA 3-group model</u>

group 1: $G1 = 0.0943C + 0.0023P - 0.0047V + 1.6625L - 9.4869$

group 2: $G2 = 0.0533C + 0.0058P - 0.0065V + 2.0950L - 14.0488$

group 3: $G3 = 0.0675C + 0.0155P - 0.0058V + 2.4968L - 27.3187$

where,

G1 = 0 accident intersections
G2 = 1 and 2 accident intersections
G3 = 3 or more accident intersections

<u>Washington, D.C. 2- group model</u>

group 1: $G1 = 0.0139C - 0.0019P - 0.0029V + 2.0773S + 0.8544L - 4.7114$

group 2: $G2 = 0.0475C - 0.0045P - 0.0038V + 0.6226S + 1.1048L - 6.9865$

<u>Seattle, WA 2-group model</u>

group 1: $G1 = 0.0934C - 0.0013P - 0.0052V + 1.5888L - 8.5028$

group 2: $G2 = 0.0505C + 0.0024P - 0.0070V + 2.0441L - 13.4090$

where,

G1 = 0 accident intersections
G2 = 1 or more accident intersections

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where,

C = conflicts
P = pedestrian volume
V = vehicle volume
S = type of control
V_p = pedestrian violations
L = number of lanes

the pedestrian signal indicated "Don't Walk" (and pedestrians complied). Therefore, many of the vehicle violations recorded may not have been violations that would have caused or been representative of pedestrian and vehicle interactions.

Research recommended is the investigation of pedestrian and vehicle violation variables that define the types of violations that lead to conflicts. Variables of this type may better aid in defining accident occurrences since some violations never endanger the pedestrian.

The P x V-conflict relationship should be further studied. As presented in this report, the P x V-conflict correlation for Washington, D.C. was 0.9374 while the P x V/-conflict correlation for Seattle, WA was 0.4828. The lower correlation in Seattle was contributed to by the sparse data that existed in this city's data base. However, if these relationships can be better defined with more data (in Seattle and other cities), the ability to predict conflicts without collecting this type of data would be economically beneficial.

Additional research using a larger intersection data base with a single accident frequency defining each group would better the utility of the model. As was shown in this study, the 3-group models were reduced to 2-group models due to the small number of intersections that were in group 3 (3 or more accidents).

In conclusion, promise has been shown in developing a pedestrian/vehicle accident prediction model using pedestrian and vehicle volumes and conflicts. As presented in the application section of this report, this model, once developed for a city, can aid the city's traffic engineer in evaluating implemented countermeasures and prioritizing hazardous sites.

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APPENDIX A - Technical Advisory Panel Members

1. Mr. Barry Fairfax, Seattle Traffic Engineering Division
2. Mr. John Fruin, PED Associates
3. Mr. Richard Knoblauch, Center for Applied Research, Inc.
4. Mr. James Migletz, Graham-Migletz Enterprises, Inc.

APPENDIX B - Data Collection Form

City ______________

Intersection ______________________________ Date __________ Coder ________________

Type of Control: A____ B____ C____ D____ Time ________

Period & Leg	Conflict Events			Violations		Volumes			
	TV	RT	LT	Pedestrian	Vehicle	Pedestrian	Vehicle		
							L	T	R

Figure 4. Pedestrian/vehicle data collection form.

APPENDIX C - Pedestrian/Vehicle Data and Variables

Table 18. Pedestrian/vehicle data and variables for Washington, D.C.

Intersection	Type of Control*	12-Hour Accidents	Number of Lanes	Conflicts TV	Conflicts RT	Conflicts LT	Conflicts Total	Pedestrian Violations	Vehicle Violations	Pedestrian Volumes	Vehicle Volumes L	Vehicle Volumes T	Vehicle Volumes R	Vehicle Volumes Total	P x V	P x V/%T	Group Number
4th & Indep.	1	4	28	1.666	48.33	9.333	59.3	46.3	24	778.3	113.3	2289	419.6	2822	361012.6	18965.54	3
4th & E St.	1	0	16	5.333	21.66	13.66	40.6	183.	72.6	508.6	188.6	599	138.3	926	80770.88	2295.245	1
1st & D St.	1	0	12	2	26	17.33	45.3	206	25.3	717.6	114	454.3	157	725.33	84210.66	2336.289	1
13th & G St.	1	0	20	11.66	109.3	71	192	219	93	2797.	232.6	1152	318.6	1703.3	798610.7	24446.89	1
5th & G St.	1	0	12	1.333	28.66	11.66	41.6	48	17.6	630	138	748.6	267	1153.6	117007.1	3312.970	1
17th & Const.	1	0	24	4	66.33	22.66	93	25.6	104.	556	104.3	3939	646	4689.3	421297.2	25175.60	1
6th & Md.	1	0	16	0.333	35.66	17	53	72.6	12	586	141.6	596	192.6	930.33	88060.22	2441.392	1
14th & K	1	8	28	6.333	133.3	43.33	183	220	257.	2114	358.3	2559.	337	3255	1132983.	53578.83	3
15th & H	1	1	12	12	175.6	57	244.	437.	133.	1938.	190.6	1470.	394.6	2055.6	642908.3	22430.32	2
18th & Mass.	1	0	12	7	62	26.33	95.3	102.	30.3	929	173.3	1729.	227	2130	332996.2	17704.58	1
Benning & MN	1	3	20	5	84	44	133	229.	107.	813.3	631	1840	502	2973	409770.5	10783.97	3
17th & H	1	2	20	13.33	235.6	88.66	337.	281	218.	2484	358.6	1672.	407.3	2438.6	1010272.	32615.17	2
8th & H St.	1	5	15	8.333	42	12	62.3	53	6.66	613.6	74.33	1690.	178.3	1943.3	200624.8	16389.11	3
7th & Indep.	1	2	28	7.333	111.3	54.33	173	82.3	227.	1207	330.3	2564.	521.3	3416	705366.7	28218.60	2
14th & P	1	4	18	2	15.33	7.666	25	31.3	19.6	374.6	150.6	1561	212	1923.6	121039.2	6500.976	3
17th & Penn.	1	1	24	19	189.3	39.33	247.	160.	126.	2385.	229.3	2773	562.6	3565	1407803.	63173.27	2
8th & E	0	1	12	8.666	5.666	6	20.3	112.	1	452.3	41.66	339	58	438.66	34450.44	1533.144	2
Garrison & WI	0	0	16	17.33	15.66	8.333	41.3	92.6	0.66	308.3	56.33	1134.	66	1256.6	65469.55	6830.590	1
CT & Morrison	0	1	16	15.33	9.666	5.333	30.3	13.6	8.33	263.6	48.33	1119.	67.33	1235.3	53346.66	6137.030	2
12th & U	0	1	12	19.66	7.333	0.666	27.6	7.66	1	167	17.66	432	32.33	482	14647.22	1545.013	2
CT & Ellicott	0	0	16	1.333	2	1.666	5	2	0.66	89	314.3	1355.	30	1700	26302.22	1376.892	1
WI & Warren	0	1	16	21.66	11.33	5.666	38.6	69	0.66	257	50	1248.	40.33	1338.6	56483.88	8578.183	2
3rd & K	0	1	8	3.333	3.666	2.333	9.33	28.6	2	129.3	15.33	147.3	27.66	190.33	4203.111	188.3855	2
3rd & C	0	0	8	5.666	5.666	5.666	17	46	8	271.3	87.66	192	102.6	382.33	17269.33	349.7424	1

* 1 - Signal Control

0 - Stop Control

Table 19. Pedestrian/vehicle data and variables for Seattle, WA.

Intersection	Type of Control*	12-Hour Accidents	Number of Lanes	Conflicts TV	RT	LT	Total	Pedestrian Violations	Vehicle Violations	Pedestrian Volumes	Vehicle Volumes L	T	R	Total	P x V	P x V/%T	Group Number
Univ. & 45th	1	4	18	5.666	69.66	0	75.3	43	11.3	1544	5	1516.	187.6	1709	470142.	40313	3
1st & Lander	1	5	22	0	1	2	3	9.66	23	47	445	1135.	411.3	1991.66	15879.6	370.59	3
5th & Broad	1	1	22	0.333	5.333	2	7.66	26.3	13	347.6	217.6	1603.	98	1919.33	110340.	6510.6	2
18th & Cherry	0	2	10	13.33	4	3	20.3	0.66	3.33	134	41.66	460.6	102	604.333	13533.6	567.94	2
12th & Spring	0	2	12	3.666	0.666	1	5.33	0	0.33	76.66	25	943	57.33	1025.33	12935.5	1617.4	2
21st & CHerry	0	1	15	0.666	0	0	0.66	0	0	16.66	23.66	456.3	44.33	524.333	1568.44	122.54	2
Broadway & Pike	1	2	20	0.666	8	4	12.6	20.6	27.3	191	137.3	1346.	196	1679.66	53446.2	2686.9	2
9th & Madison	1	2	18	3.333	1.333	3.666	8.33	16.6	15.6	228	138	1013.	216.6	1368.33	52424.4	2087.6	2
Rainer & Clov.	1	1	19	0.333	1	1	2.33	8	12.3	44	89.66	1090	78.33	1258	9799.33	723.86	2
14th & Clover.	1	1	16	0.333	0.333	2	2.66	7	17.3	54.33	305.6	707.3	288	1301	11403.4	249.19	2
Fremont & 35th	1	1	20	0	0	0	0	10.6	17	89	340	649	195.6	1184.66	17996.4	392.30	2
26th & Roxbury	1	1	19	0.666	1.666	1	3.33	1.66	2.33	28.66	117	966.6	142.3	1226	5925.44	282.31	2
Brooklyn & 47th	0	1	16	1.333	0.666	0	2	0.33	1	154	71.66	228.6	80.66	381	10938.8	266.63	2
12th & King	0	1	17	3	0.333	1	4.33	1	0	26	123.3	682.6	144	950	4189.55	151.23	2
8th & Market	1	2	19	0.333	6.666	1.333	8.33	7.33	91.3	81.66	255	1516.	212.3	1984	28777.6	1246.1	2
Western & VA	0	1	11	1.333	0.333	0.333	2	10.3	0.33	527.3	461.6	396.6	190	1048.33	106334.	1593.6	2
Coaliss & 45th	0	1	12	4.333	1.666	0.333	6.33	0.66	6.33	75	41.33	531.3	236.3	809	10962.5	318.91	2
2nd & Roy	0	0	10	5	2	0	7	8	4.33	82	160.3	170	105	435.333	5938	97.975	1
34th & Dravus	0	0	10	0	0	0	0	0	0	13.66	7	221	11.33	239.333	552.555	101.35	1
West. & Spring	0	0	10	57.33	12	16.33	85.6	43.3	7	419.6	114	610	112.6	836.666	59326.4	2156.4	1
8th & 85th	1	0	17	0	4	0.333	4.33	1.33	6.33	26.33	257	1259	193	1709	7633.44	291.55	1
3rd & 85th	1	0	15	1.333	2.666	1	5	3.66	14.6	76.66	261.3	1269.	136.3	1667.33	21859.7	914.13	1
Brooklyn & 40th	0	0	11	8	2.666	4.666	15.3	14.3	10.6	246.3	54.33	260.3	54.66	369.333	15425.7	534.67	1
Olive & Boren	1	0	18	0	1	1.333	2.33	7.66	16.6	130	76.33	1311.	184	1571.66	34845	2107.7	1

* 1 - Signal Control

0 - Stop Control

APPENDIX D - Discussion of Discriminant Analysis

Discriminant analysis models group type variables (1, 2, 3, etc.) using discriminanting variables. Figure 5 shows a conceptual diagram of two discriminanting variables, X1 and X2, defining Groups 1, 2, and 3. X1 and X2 act as independent variables defining a dependent variable, group number. Depending on the coordinate of X1 and X2, a group is identified if this coordinate lies inside a group's boundary.

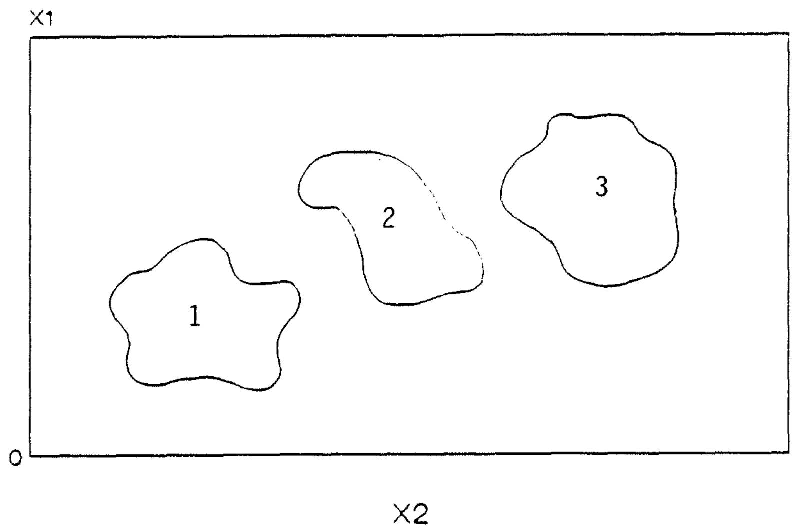


Figure 5. Conceptual model of discriminant modeling.

Each group is defined by a linear equation and presented below. Values of X1 and X2 are substituted into all group equations. The group which best defines these variables is the group with the largest value. With respect to the diagram (figure 5), two of the below group values will be zero since the specific values of X1 and X2 can only lie in one group. However, groups do not have distinct boundaries as shown in this diagram.

Group 1 = C1(X1) + C2(X2) + C3

Group 2 = C4(X1) + C5(X2) + C6

Group 3 = C7(X1) + C8(X2) + C9

where:

C1, C2,..., C9 = constants

Figure 6 demonstrates group overlap which is caused by the variation that exists in the discriminanting variables. When group overlap occurs, all the group equations will result a value. Thus, the group with the largest value will be the group which best defined the values of X1 and X2.

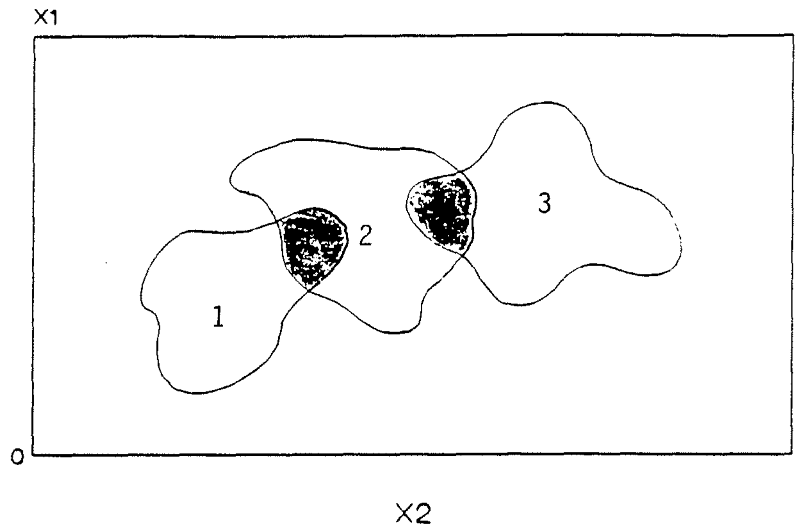


Figure 6. Group overlap.

The evaluation of the accuracy of a discriminant model (all group equations) depends on the number of correct groups that are identified by the variables in the model. In other words, each set of X1 and X2 variables were initially identified by a group (1, 2, or 3), thus, based on the model, all sets of variables should define their initial group number. However, depending on these varibles' variations and their true relationship with their group indication, they may not define their initial group.

Shown on the next page is a classification matrix that the discriminant analysis procedure produces. The column labeled GROUP identifies the initial group that the variables were in. The EXPECTED GROUP column indicates the groups in the model. Lastly, the NUMBER column indicates the groups which the variables defined. To determine the accuracy of the model, the percentage of correctly identified groups is calculated. From this matrix, the percentage is 62.5% (15/24). This percentage was hampered primarily by the poor results in Group 1, thus, additional variables may need to be entered into the model to better define this group and improve the accuracy of the model.

CLASSIFICATION MATRIX

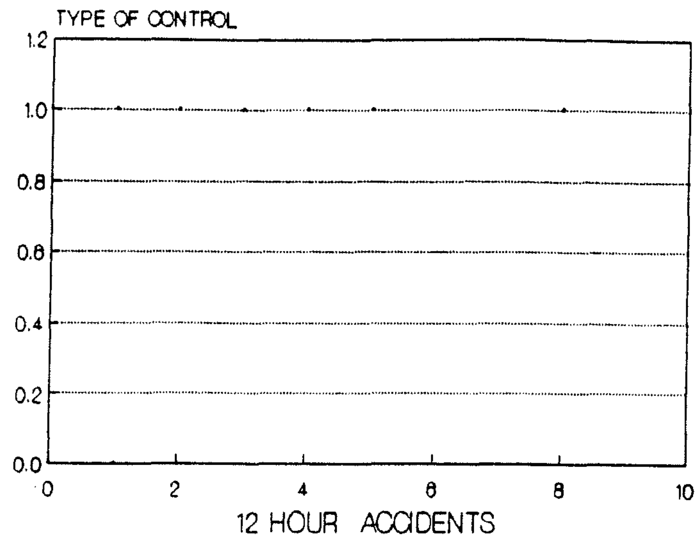
GROUP	EXPECTED GROUP	NUMBER	
1	1	1	
1	2	5	
1	3	1	
		TOTAL =	7
2	1	2	
2	2	13	
2	3	0	
		TOTAL =	15
3	1	0	
3	2	1	
3	3	1	
		TOTAL =	2

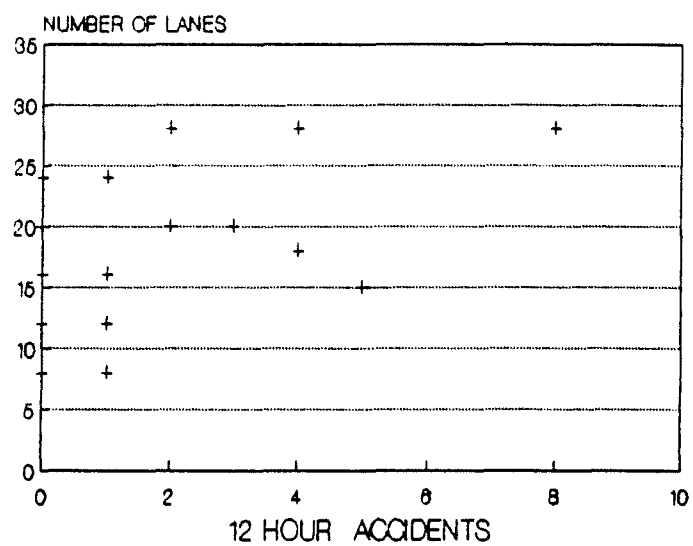
For additional information on discriminant analysis refer to the following reference.

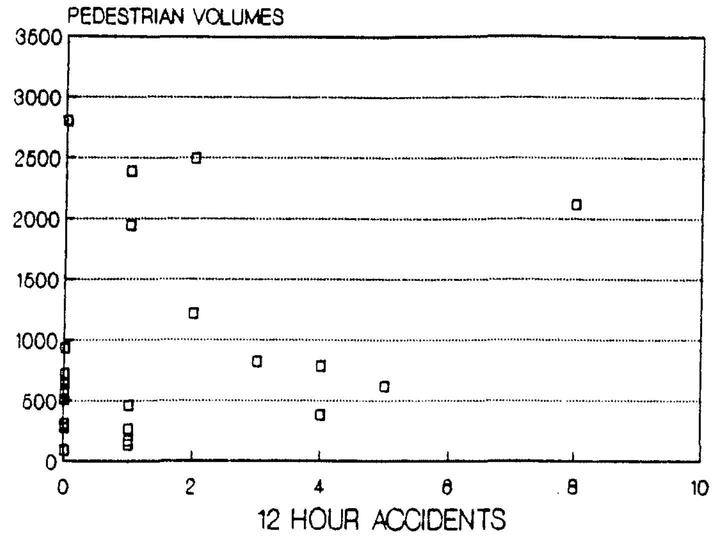
Nordcliff, G.B. Inferential Statistics for Geographers: An Introduction. 2nd Ed. Hutchinson & Co. Ltd., London, 1982.

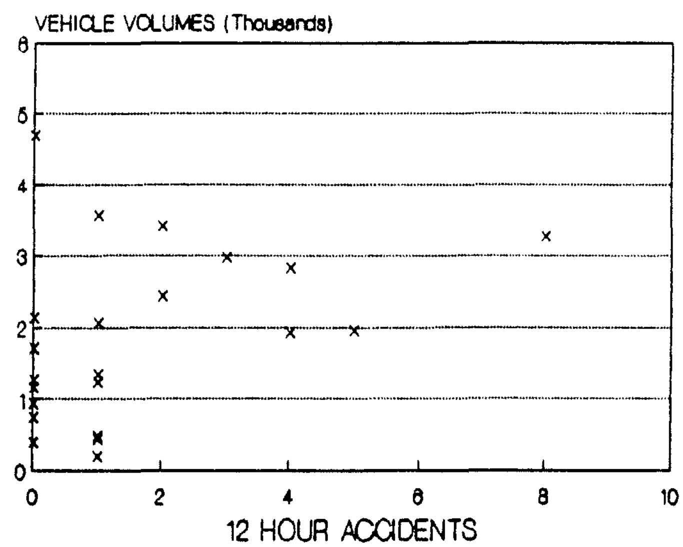
APPENDIX E -

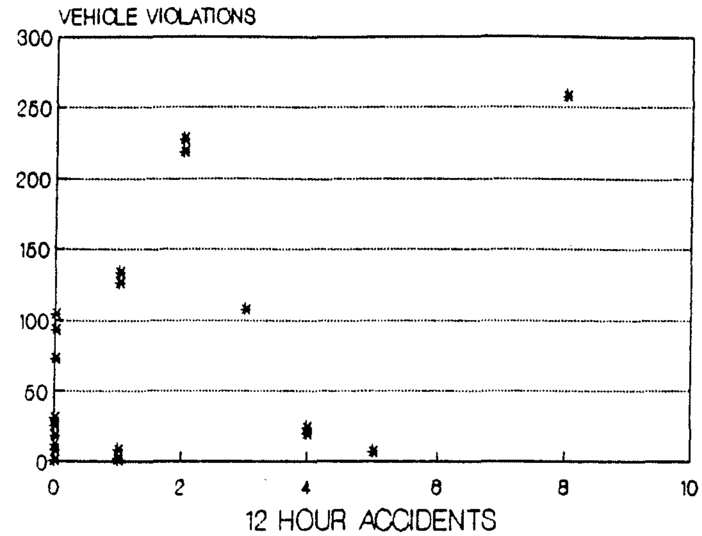
12-Hour Scatter Diagrams for Washington, D.C.

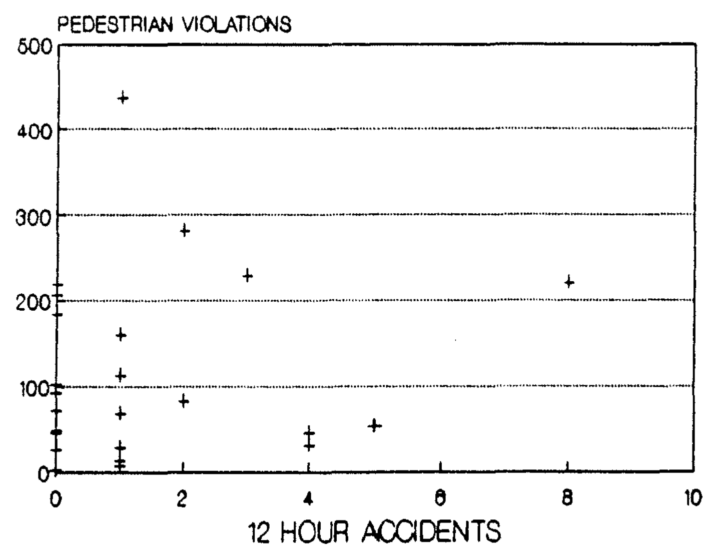

TYPE OF CONTROL
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12 HOUR ACCIDENTS

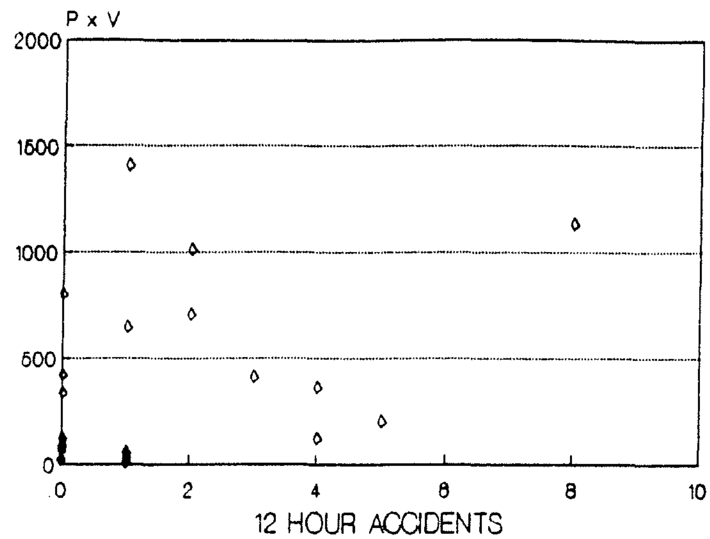

NUMBER OF LANES
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12 HOUR ACCIDENTS

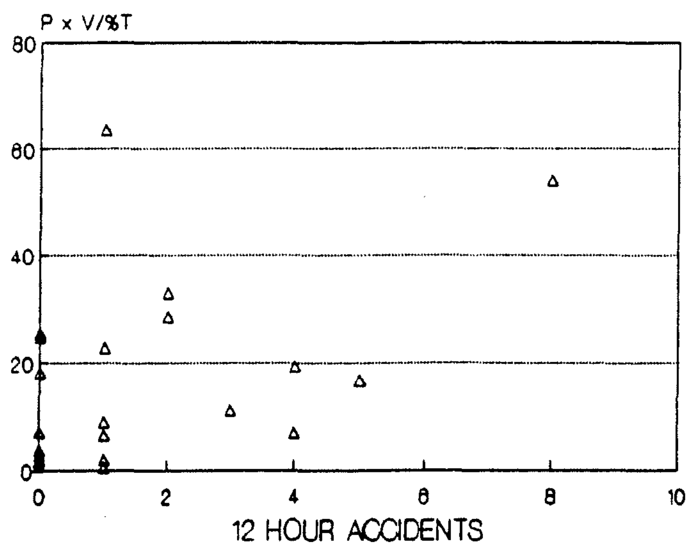

PEDESTRIAN VOLUMES
3500
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12 HOUR ACCIDENTS

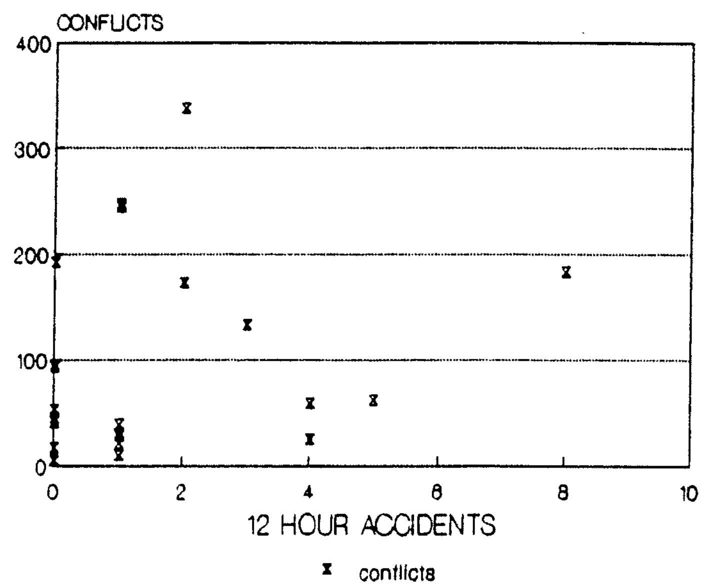

VEHICLE VOLUMES (Thousands)
6
5
4
3
2
1
0
0
2
4
6
8
10
12 HOUR ACCIDENTS


VEHICLE VIOLATIONS
300
250
200
150
100
50
0
0
2
4
6
8
10
12 HOUR ACCIDENTS


PEDESTRIAN VIOLATIONS
500
400
300
200
100
0
0
2
4
6
8
10
12 HOUR ACCIDENTS

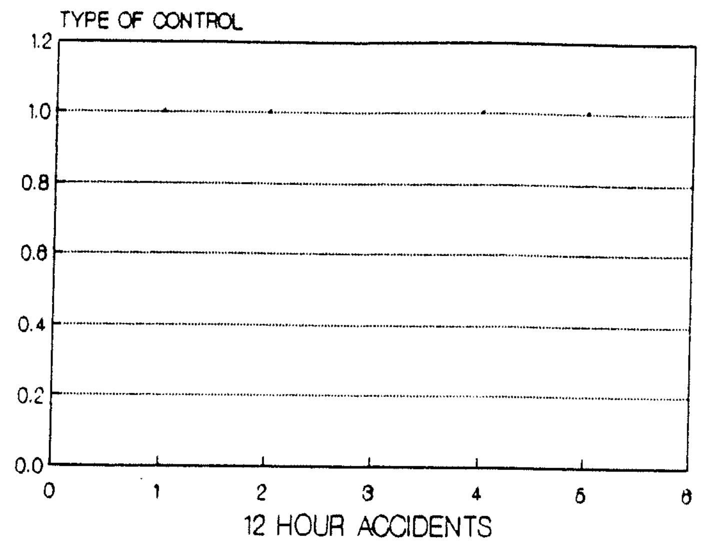

P x V
2000
1500
1000
500
0
0
2
4
6
8
10
12 HOUR ACCIDENTS

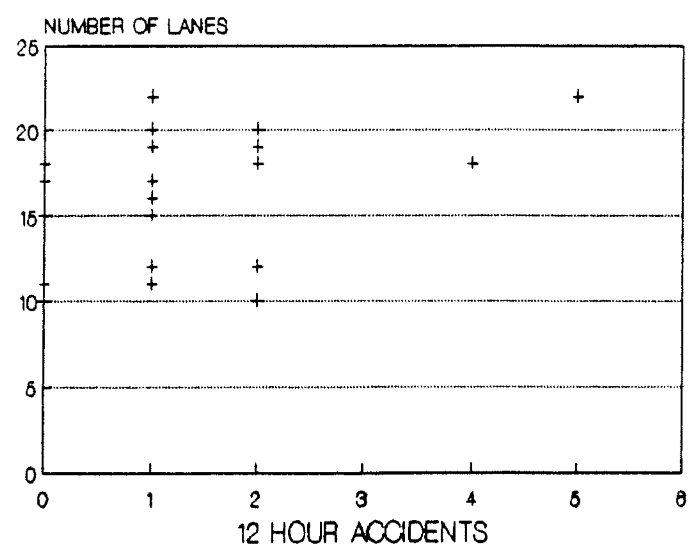

P x V/%T
80
60
40
20
0
0
2
4
6
8
10
12 HOUR ACCIDENTS

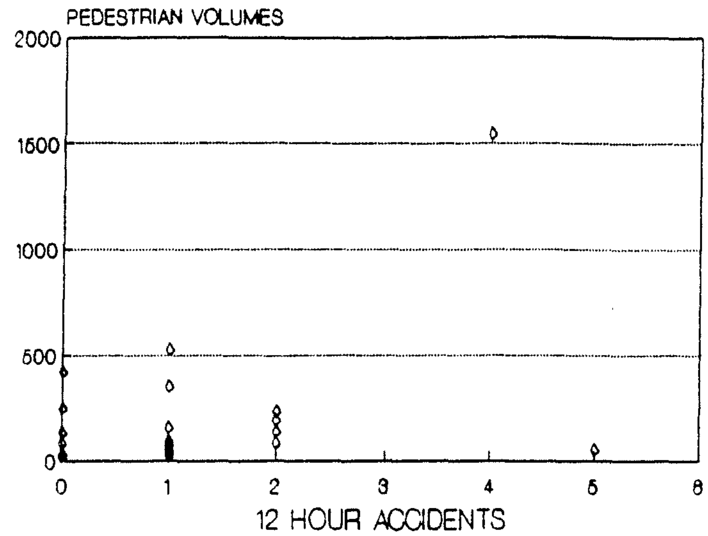

CONFLICTS
400
300
200
100
0
0
2
4
6
8
10
12 HOUR ACCIDENTS
conflicts

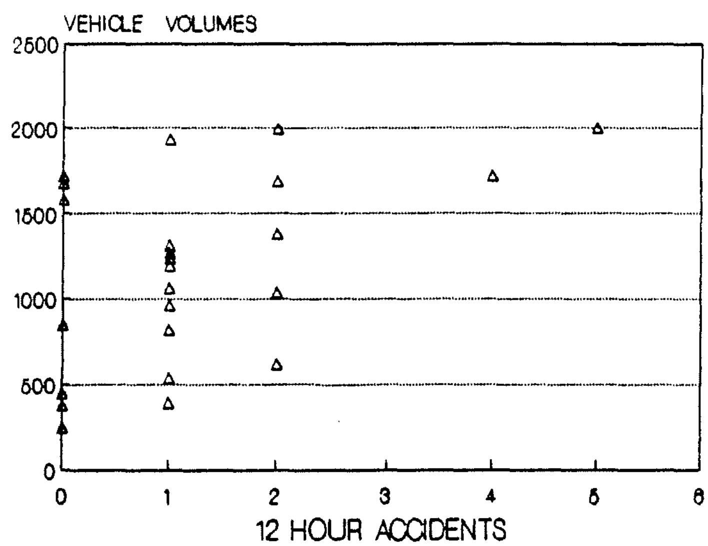
APPENDIX F -

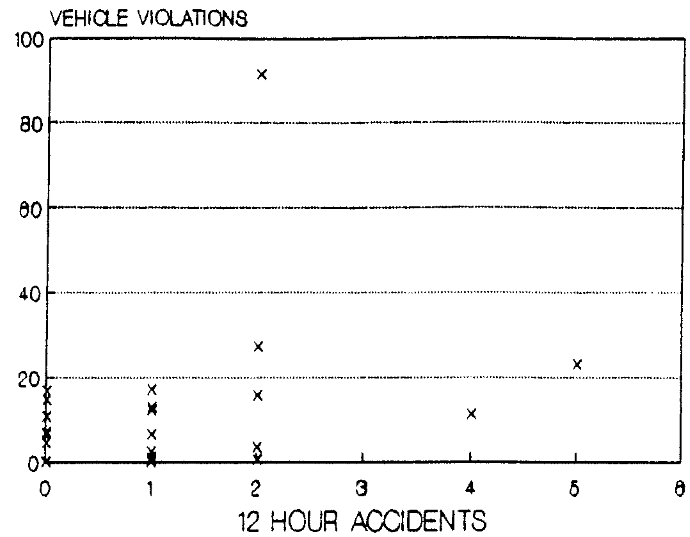
12-Hour Scatter Diagrams for Seattle, WA

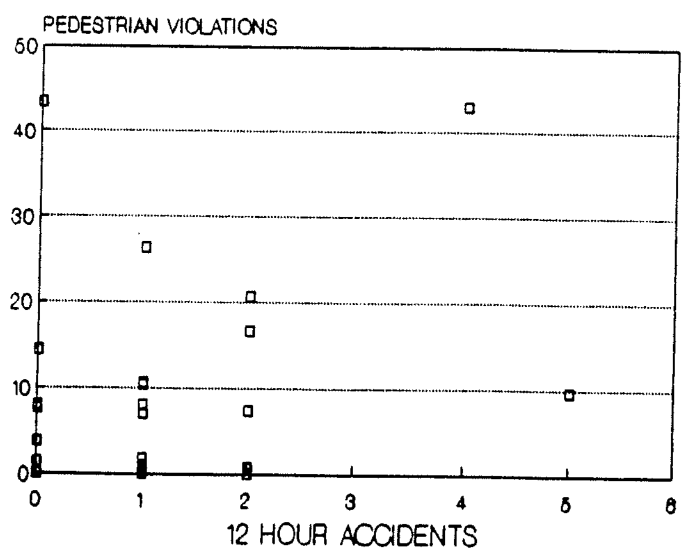

TYPE OF CONTROL
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
12 HOUR ACCIDENTS

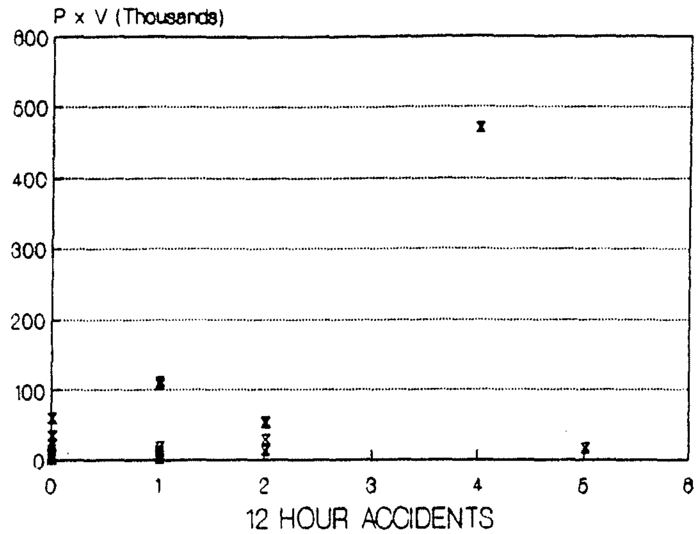

NUMBER OF LANES
25
20
15
10
5
0
0
1
2
3
4
5
6
12 HOUR ACCIDENTS

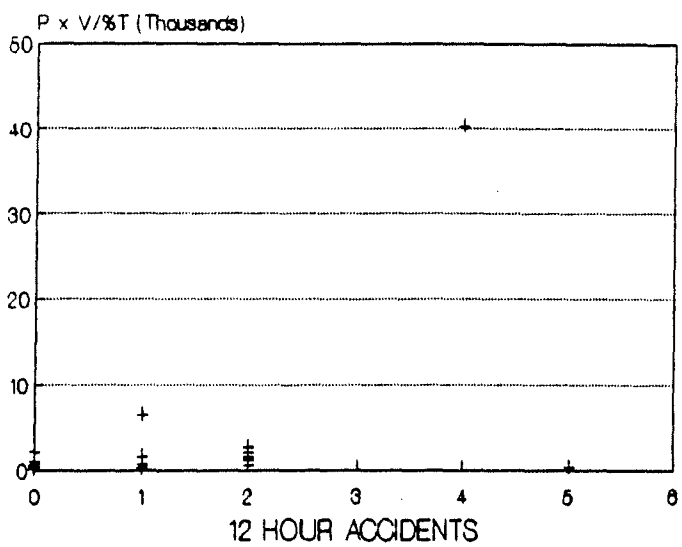

PEDESTRIAN VOLUMES
2000
1500
1000
500
0
0
1
2
3
4
5
6
12 HOUR ACCIDENTS

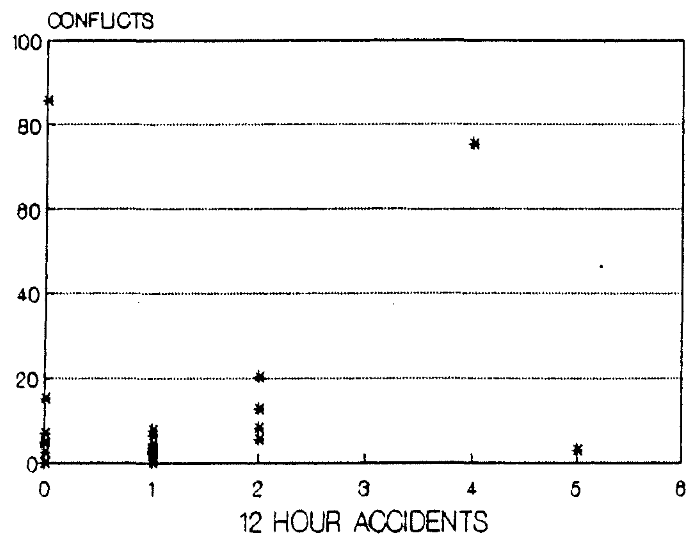

VEHICLE VOLUMES
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
12 HOUR ACCIDENTS


VEHICLE VIOLATIONS
100
80
60
40
20
0
0
1
2
3
4
5
6
12 HOUR ACCIDENTS


PEDESTRIAN VIOLATIONS
50
40
30
20
10
0
0
1
2
3
4
5
6
12 HOUR ACCIDENTS


P x V (Thousands)
600
500
400
300
200
100
0
0
1
2
3
4
5
6
12 HOUR ACCIDENTS


P x V/%T (Thousands)
50
40
30
20
10
0
0
1
2
3
4
5
6
12 HOUR ACCIDENTS


CONFLICTS
100
80
60
40
20
0
0
1
2
3
4
5
6
12 HOUR ACCIDENTS

APPENDIX G -

Washington, D.C. Equations and Classification Matrices (3-group models)

The following discriminant analysis outputs were of models that did not produce significant results or improve the optimum model. The variable definitions are:

- CON - Conflicts
- PED - Pedestrian Volume
- VEH - Vehicle Volume
- VOP - Pedestrian Violations
- VOV - Vehicle Violations
- LN - Number of Lanes
- SN - Type of Control
- PXV - Pedestrian-Vehicle Volume Product
- PXV/T - Pedestrian-Vehicle Volume Product/Percent Turning Vehicles

DISCRIMINATION COEFFICIENTS

		GROUP 1	GROUP 2	GROUP 3
CONSTANT		-3.7455	-1.8706	-6.3737
	CON	-0.0723	-0.0017	-0.0910
	PED	0.0042	0.0006	0.0045
	VEH	0.0031	0.0020	0.0041
	SN	3.4415	-1.0756	4.8480
	VOV	-0.0231	-0.0183	-0.0176
	VOP	0.0246	0.0146	0.0272

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER		
1	1	7		
1	2	2		
1	3	1		
		TOTAL	=	10
2	1	0		
2	2	9		
2	3	0		
		TOTAL	=	9
3	1	1		
3	2	0		
3	3	4		
		TOTAL	=	5

DISCRIMINATION COEFFICIENTS

		GROUP 1	GROUP 2	GROUP 3
CONSTANT		-2.5967	-1.4660	-4.9720
	CON	-0.0399	0.0176	-0.0552
	PED	0.0035	0.0002	0.0037
	VEH	0.0018	0.0012	0.0026
	SN	4.2059	-0.6220	5.6924
	VOV	-0.0171	-0.0148	-0.0110

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER		
1	1	6		
1	2	3		
1	3	1		
		TOTAL	=	10
2	1	0		
2	2	8		
2	3	1		
		TOTAL	=	9
3	1	1		
3	2	0		
3	3	4		
		TOTAL	=	5

DISCRIMINATION COEFFICIENTS

		GROUP 1	GROUP 2	GROUP 3
CONSTANT		-2.3490	-1.2820	-4.8704
	CON	-0.0502	0.0087	-0.0618
	VEH	0.0015	0.0009	0.0024
	PED	0.0035	0.0002	0.0037
	SN	4.1682	-0.6545	5.6682

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER	
1	1	5	
1	2	3	
1	3	2	
		TOTAL =	10
2	1	0	
2	2	9	
2	3	0	
		TOTAL =	9
3	1	0	
3	2	0	
3	3	5	
		TOTAL =	5

DISCRIMINATION COEFFICIENTS

		GROUP 1	GROUP 2	GROUP 3
CONSTANT		-0.2416	-0.9759	-0.5307
	CON	0.0077	0.0156	0.0115

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER	
1	1	7	
1	2	1	
1	3	2	
		TOTAL =	10
2	1	5	
2	2	4	
2	3	0	
		TOTAL =	9
3	1	3	
3	2	2	
3	3	0	
		TOTAL =	5

DISCRIMINATION COEFFICIENTS

		GROUP 1	GROUP 2	GROUP 3.
CONSTANT		-0.1273	-0.5878	-0.6109
	PXV	1.2532E-06	2.6926E-06	2.7449E-06

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER		
1	1	7		
1	2	2		
1	3	1		
		TOTAL	=	10
2	1	5		
2	2	0		
2	3	4		
		TOTAL	=	9
3	1	2		
3	2	2		
3	3	1		
		TOTAL	=	5

APPENDIX H -

Seattle, WA Equations and Classification Matrices (3-group models)

The following discriminant analysis outputs were of models that did not produce significant results or improve the optimum model. The variable definitions are:

- CON - Conflicts
- PED - Pedestrian Volume
- VEH - Vehicle Volume
- VOP - Pedestrian Violations
- VOV - Vehicle Violations
- LN - Number of Lanes
- SN - Type of Control
- PXV - Pedestrian-Vehicle Volume Product
- PXV/T - Pedestrian-Vehicle Volume Product/Percent Turning Vehicles

DISCRIMINATION COEFFICIENTS

		GROUP 1	GROUP 2	GROUP 3
CONSTANT		-0.3553	-0.0403	-1.8650
	CON	0.0416	0.0140	0.0952

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER	
1	1	1	
1	2	5	
1	3	1	
		TOTAL =	7
2	1	2	
2	2	13	
2	3	0	
		TOTAL =	15
3	1	0	
3	2	1	
3	3	1	
		TOTAL =	2

DISCRIMINATION COEFFICIENTS

		GROUP 1	GROUP 2	GROUP 3
CONSTANT		-18.1427	-27.6279	-45.7064
	CON	0.0571	0.0067	0.0133
	PED	0.0064	0.0109	0.0214
	VEH	0.0042	0.0048	0.0073
	LN	2.9564	3.7157	4.3826
	SN	-19.1859	-24.0305	-27.9635

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER	
1	1	6	
1	2	1	
1	3	0	
		TOTAL =	7
2	1	3	
2	2	11	
2	3	1	
		TOTAL =	15
3	1	0	
3	2	1	
3	3	1	
		TOTAL =	2

DISCRIMINATION COEFFICIENTS

	GROUP 1	GROUP 2	GROUP 3
CONSTANT	-15.2756	-24.4939	-40.7773
PXV/T	0.0003	0.0003	0.0009
SN	-15.7993	-20.0534	-22.9416
LN	2.8464	3.6056	4.3033

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER	
1	1	6	
1	2	1	
1	3	0	
		TOTAL =	7
2	1	4	
2	2	11	
2	3	0	
		TOTAL =	15
3	1	0	
3	2	1	
3	3	1	
		TOTAL =	2

DISCRIMINATION COEFFICIENTS

		GROUP 1	GROUP 2	GROUP 3
CONSTANT		-15.8417	-25.4825	-42.0284
	PXV	2.6707E-05	3.4519E-05	7.6039E-05
	SN	-16.2932	-20.7131	-23.6495
	LN	2.9252	3.7104	4.4282

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER	
1	1	6	
1	2	1	
1	3	0	
		TOTAL =	7
2	1	5	
2	2	9	
2	3	1	
		TOTAL =	15
3	1	0	
3	2	1	
3	3	1	
		TOTAL =	2

DISCRIMINATION COEFFICIENTS

		GROUP 1	GROUP 2	GROUP 3
CONSTANT		-0.3583	-0.1369	-4.3803
	CON	0.0452	-0.0068	-0.0110
	PED	-0.0004	0.0023	0.0116

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER	
1	1	1	
1	2	6	
1	3	0	
		TOTAL =	7
2	1	1	
2	2	13	
2	3	1	
		TOTAL =	15
3	1	0	
3	2	1	
3	3	1	
		TOTAL =	2

DISCRIMINATION COEFFICIENTS

		GROUP 1	GROUP 2	GROUP 3
CONSTANT		-0.0098	-0.0196	-5.1666
	PXV/T	2.2132E-05	3.1327E-05	0.0005

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER		
1	1	5		
1	2	2		
1	3	0		
		TOTAL	=	7
2	1	9		
2	2	6		
2	3	0		
		TOTAL	=	15
3	1	1		
3	2	0		
3	3	1		
		TOTAL	=	2

DISCRIMINATION COEFFICIENTS

		GROUP 1	GROUP 2	GROUP 3
CONSTANT		-0.0368	-0.0769	-5.0302
	PXV	3.5430E-06	5.1173E-06	4.1399E-05

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER		
1	1	5		
1	2	2		
1	3	0		
		TOTAL	=	7
2	1	10		
2	2	5		
2	3	0		
		TOTAL	=	15
3	1	1		
3	2	0		
3	3	1		
		TOTAL	=	2

APPENDIX I -

Washington, D.C. Equations and Classification Matrices (2-group models)

The following discriminant analysis outputs were of models that did not produce significant results or improve the optimum model. The variable definitions are:

- CON - Conflicts
- PED - Pedestrian Volume
- VEH - Vehicle Volume
- VOP - Pedestrian Violations
- VOV - Vehicle Violations
- LN - Number of Lanes
- SN - Type of Control
- PXV - Pedestrian-Vehicle Volume Product
- PXV/T - Pedestrian-Vehicle Volume Product/Percent Turning Vehicles

DISCRIMINATION COEFFICIENTS

		GROUP 1	GROUP 2
CONSTANT		-1.2656	-1.5848
	CON	-0.0262	-0.0032
	PED	0.0028	0.0009
	VEH	0.0013	0.0013

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER		
1	1	7		
1	2	3		
		TOTAL	=	10
2	1	8		
2	2	6		
		TOTAL	=	14

DISCRIMINATION COEFFICIENTS

		GROUP 1	GROUP 2
CONSTANT		-6.1062	-8.3129
	PED	-0.0032	-0.0032
	VEH	-0.0026	-0.0026
	SN	0.7469	-1.1483
	LN	1.0221	1.1878
	VOP	0.0257	0.0315

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER		
1	1	6		
1	2	4		
		TOTAL	=	10
2	1	4		
2	2	10		
		TOTAL	=	14

DISCRIMINATION COEFFICIENTS

		GROUP 1	GROUP 2
CONSTANT		-1.4861	-1.5941
	CON	-0.0251	-0.0029
	PED	0.0023	0.0008
	VEH	0.0010	0.0012
	SN	1.8980	0.3908

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER	
1	1	7	
1	2	3	
		TOTAL =	10
2	1	5	
2	2	9	
		TOTAL =	14

DISCRIMINATION COEFFICIENTS

		GROUP 1	GROUP 2
CONSTANT		-6.1682	-8.4385
	PED	-0.0021	-0.0048
	VEH	-0.0022	-0.0031
	SN	0.5642	-0.8880
	CON	-0.0139	0.0198
	VOP	0.0281	0.0281
	LN	0.9873	1.2374

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER	
1	1	8	
1	2	2	
		TOTAL =	10
2	1	4	
2	2	10	
		TOTAL =	14

APPENDIX J -

Seattle, WA Equations and Classification Matrices (2-group models)

The following discriminant analysis outputs were of models that did not produce significant results or improve the optimum model. The variable definitions are:

- CON - Conflicts
- PED - Pedestrian Volume
- VEH - Vehicle Volume
- VOP - Pedestrian Violations
- VOV - Vehicle Violations
- LN - Number of Lanes
- SN - Type of Control
- PXV - Pedestrian-Vehicle Volume Product
- PXV/T - Pedestrian-Vehicle Volume Product/Percent Turning Vehicles

DISCRIMINATION COEFFICIENTS

		GROUP 1	GROUP 2
CONSTANT		-16.0075	-25.5892
	CON	0.0563	0.0033
	PED	0.0010	0.0052
	VEH	0.0030	0.0035
	LN	2.7366	3.5064
	SN	-17.9730	-22.8972

CLASSIFICATION MATRIX

GROUP	EXPECTED GROUP	NUMBER		
1	1	6		
1	2	1		
		TOTAL	=	7
2	1	3		
2	2	14		
		TOTAL	=	17