Pedestrian/Vehicle Conflicts: An Accident Prediction Model

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Traffic conflicts have been used to define the potential for traffic accidents. However, conflicts defined by vehicle and pedestrian interactions have not produced reliable techniques to explain pedestrian/vehicle accidents. This study was conducted to determine the relationship between pedestrian/vehicle conflicts and accidents in order to develop a reliable model to predict the occurrence of pedestrian accidents. Accident group models were developed using discriminate analysis for the cities of Washington, D.C., and Seattle. Along with counting the conflicts that were used to define these accident groups, exposure measures such as pedestrian volume, vehicle volume, number of lanes, and type of traffic control aided in the explanation of pedestrian accident variance. Further research was recommended to investigate refined variable definitions along with the use of a larger accident data base.

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 evasive action, that is, a change in direction, speed, or both, in order to avoid a collision. Several studies (*1–3*) have been conducted to determine the relationship between 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. Because of this lack of research, reliable pedestrian/vehicle conflict analysis techniques have not yet been developed.

In recent studies (*4, 5*), 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 yet produced adequate and sensitive analysis techniques or methods. Along with the lack of research in this area is the difficulty of defining 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. Then the ability to identify or predict sites where pedestrian accidents would occur would allow preemptive actions to be taken to avoid these types of accidents. In 1985, the Federal Highway Administration sponsored a study to investigate this relationship (*6*).

The objectives of this study were to synthesize existing information on pedestrian/vehicle conflicts, determine the relationship of pedestrian-related conflicts to pedestrian accidents, and develop methods to obtain reliable pedestrian conflict data.

The study was concerned with a thorough examination of the various methods and techniques of measuring vehicle/pedestrian conflicts. Traffic conflict techniques were identified and evaluated in terms of their potential usefulness in defining and developing pedestrian/vehicle conflicts; data requirements; data collection procedures; cost-effectiveness; uses of data; and other evaluation criteria such as accuracy of data, ease of data collection, and feasibility of methodology. In addition, behavioral and exposure measures were investigated in terms of their usefulness in defining pedestrian/vehicle conflicts and developing accident-potential criteria, respectively.

A literature review was conducted to identify methods of measuring vehicle and pedestrian conflicts. 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.

RESEARCH METHODOLOGY

Most studies from the literature review dealt with vehicle/vehicle conflicts and accidents. Some studies considered the pedestrian/vehicle conflict only as a vehicle hindrance whereas others acknowledged it only in passing. In contrast, this study's primary objective was to examine pedestrian/vehicle conflicts.

The pedestrian conflict measures used by Robertson et al. (*7*) and Zegeer et al. (*8*) primarily dealt with pedestrian behaviors. Conflict-behavior measures were used in before-and-after-type studies to determine pedestrian behavior responses to different pedestrian signalization alternatives. Therefore, their research objectives did not address the accident prediction problem.

Cynecki (*9*), on the other hand, used his pedestrian/vehicle conflict measures as accident-potential indicators. He used 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 one more narrowly focused.

Exposure measures have been used to define high-risk locations for pedestrians. Exposure was seen by Cameron et al. (*5*) as the product of pedestrian volume (P) and vehicle vol-

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ume (V), $P \times V$. They stated that pedestrian accident risk cannot occur where both pedestrian and vehicle volumes do not exist. Robertson (*10*) used a $P \times V$ exposure measure but added turning volume (T). The introduction of turning volumes, as explained by Mackie and Older (*4*), into a $P \times V$ exposure strengthens the accident-exposure measure relationship.

Pedestrian and vehicle violations were used in the studies of Cynecki (*9*) and Zegeer et al. (*8*). Cynecki used both violations as conflict measures (violations that produced conflicts) whereas Zegeer et al. recorded only pedestrian violations. Neither study discussed risk or the accident-violation relationship.

The first approach of this study was to investigate the pedestrian/vehicle conflict-accident relationship in two cities. Some of the studies (*7, 9*) 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 probably was to increase accident variation and total number of accidents since pedestrian accidents are rare occurrences. However, the use of this type of data did not consider differences that may exist in each state or city between pedestrian and vehicle (driver) behaviors, patterns, volume variations, controls, and laws. This study recognized those differences. Some cities may be highly urbanized, resulting in a relatively greater number of pedestrian and vehicle volumes, violations, and conflicts. In cities that are less densely populated, volumes, violations, and conflicts may be lower. An intersection in either type city may experience one accident in 3 years but under quite 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 lack of accident variation. Stratified or grouped accident data ensure the user of obtaining a broader range of accidents, thus optimizing accident variation. 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 analysis techniques. The accidents of this study are considered to be grouped ordinal data, and techniques such as Pearson correlations and regression could not be used since both require nominal data.

Keeping in mind the accident data base characteristics that were possible, alternative analysis techniques for handling these types of data were considered. Thus, stratifying the accident data allowed for pre-examination of applicable analysis techniques.

DATA COLLECTION

The data collection effort consisted of three parts: (a) a trial field test, (b) the collection of pedestrian/vehicle conflict data, and (c) 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 sample of pedestrians crossing at three intersections in Washington, D.C., was recorded on videotape during the morning, midday, and afternoon peak hours. Key members of the research team viewed the tape together and collectively evaluated the occurrence of nine conflict measures used in previous studies (*6*). On the basis of this evaluation and input from a Technical Advisory Panel, three of the nine conflict measures were modified and selected for use as measures of effectiveness in the field data collection effort. The conflicts are listed in Table 1.

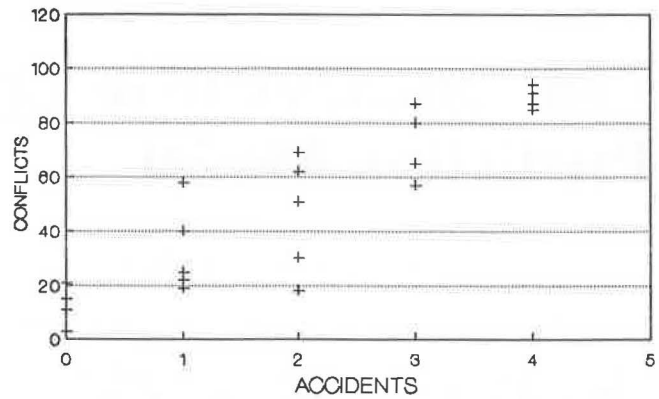

FIGURE 1 Example of grouped accident data.

Collection of Pedestrian/Vehicle Conflict Data

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

Intersection characteristic data were obtained for the total population of four approach intersections (signalized and unsignalized) in Washington, D.C., and Seattle. 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 below. The volumes at the sampled intersections were checked to ensure that there was 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 the test results.

The intersections samples were stratified with respect to type of control and pedestrian accident frequency. Noting that several past studies have shown some relationship between pedestrian accidents and volume, the sample was not stratified by pedestrian or vehicle volume in order to avoid a possible duplicate control.

The procedure used 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.

TABLE 1 PEDESTRIAN/VEHICLE CONFLICTS SELECTED 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.

2. Each accident group was subdivided into two subgroups with respect to type of control, that is, signalized or unsignalized.
3. From each of the 6 sub-subgroups, 48 intersections were drawn at random, 24 in each city.

In Seattle, 13 signalized and 11 unsignalized intersections were selected and in Washington, D.C., 16 and 8, respectively. A higher number of signalized intersections were chosen because of low-accident frequencies that existed in the nonsignalized intersection group.

Data were collected manually using field observers provided with push-button-type counting devices. Because 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 that offered a clear view of the crosswalk and approaches. For low- to moderate-volume intersections, one observer was used, whereas high-volume intersections required two observers operating as a team.

Each crosswalk (and approach) was observed for one signal cycle per 5 min at signalized intersections or for a 5-min period at unsignalized intersections. The data collected included conflicts, pedestrian and vehicle counts, and compliance. Thus, each approach was sampled at least three times during each data collection hour. At high-volume intersections, one observer coded conflicts and noncompliance, which included walking against the signal and vehicles running the red signal or stop sign, whereas the second observer counted pedestrians and vehicles. 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 6 hr per day from 7:00 a.m. to 9:00 a.m., 11:00 a.m. to 1:00 p.m. and 4:00 p.m. to 6:00 p.m. Approximately 2½ wk of data were collected for each city for three seasons (6 hr per season per site): spring (March, April), summer (July, August), and autumn (October, November).

Collection of Accident Data

Accident data served two purposes in this project. First, the data were used as a (stratification) criterion for site selection, and second, 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 were obtained either directly from the city if available, or computed from the counts made during field data collection. Pedestrian accident data were obtained from city department of transportation records at each site for a period of 3 yr before the start of data collection and continuing for the duration of data collection. Data elements of interest included type of accident, (i.e., object struck), time of day, day of week, month of year, and severity. There were approximately 50 to 60 pedestrian accidents in each city's data base.

DATA ANALYSIS

Different pedestrian and vehicle volume magnitudes and distributions exist between weekdays and weekends. Therefore, the conflict data were collected for weekdays only, and accidents that occurred on weekends were deleted from each intersection data base. In addition to removing weekend accidents, the accidents that occurred outside of the 6-hr data collection period were initially removed. Winter accidents that occurred in January and February were removed because the data collection effort encompassed spring, summer, and autumn months.

Tables 2 and 3 present 24-hr (7-day), 12-hr (7:00 a.m. to 7:00 p.m.), and 6-hr data collection period accident frequencies for each intersection in both cities. In reviewing the 6-hr accident variation, large groupings of 0- and 1-accident intersections were noted. Thus, to increase the number of accidents

TABLE 2 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

TABLE 3 ACCIDENT FREQUENCIES FOR SEATTLE

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

and still have the 6-hr conflict data representative of the pedestrian/vehicle accidents, the 12-hr accidents for each intersection were used in the data analysis.

The conflict data included through, right-turn, and left-turn conflicts as defined in the data collection section; pedestrian and vehicle violations; pedestrian volumes; and left-turn, through, and right-turn vehicle volumes.

From the state-of-the-practice, two computed exposure measures were selected for use in the analysis: (a) the product of pedestrian volume and vehicle volume ($P \times V$) and (b) the pedestrian and vehicle volume product divided by percentage of vehicle turns ($P \times V/\%T$). These exposure measures were computed on the basis of sum of 1-hr products. These two measures, along with the additional data collected in this study, are presented in Tables 4 and 5. Conflicts, violations, and volumes are computed on the basis of 6-hr seasonal averages.

The cities of Washington, D.C., and Seattle were analyzed separately because of the differences in their accident frequencies, conflict occurrences, and pedestrian and vehicle volumes. In a comparison between the two cities' data bases, the intersections sampled in Seattle had fewer accidents and conflict events and lower volumes.

The analysis effort was directed toward group modeling because correlating the stratified accident data with the collected data would not have produced usable results.

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

The state-of-the-practice study showed that conflicts have been used in defining potential pedestrian and vehicle accident sites and that 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 total number of intersection approach lanes, pedestrian/vehicle conflicts, pedestrian volumes (P) and vehicle volumes (V), and the products of $P \times V$ and $P \times V/\%T$. In addition to these variables, type of traffic control and vehicle and pedestrian violations were also used.

Because 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. Table 6 was generated from the discriminate analysis procedure. The column labeled "Number" is the number of observations assigned to the expected group based on the equations derived in the discriminate analysis process. Using Group 1 (0-accident intersections) as 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, one intersection fell into group 2, and two into group 3. Thus for the equations based on pedestrian and vehicle volumes, 70 percent of the intersections were placed into the appropriate Group 1. Overall, 15 of the 24 intersections (62.5 percent) were placed into the 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 would help explain the variation in Group 2. The next variable entered was total conflicts.

For Group 3 in Table 7, the accuracy of the prediction was reduced from 80 to 60 percent with the addition of conflicts into the model. This type of occurrence is a result of the negative effect of conflicts in Group 3. When variables are added to the models (Groups 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 because some variable values are found in more than one group. Therefore, one or two intersections in Group 3 were best defined (by conflicts) to reside in Groups 1 and 2 because conflict similarities of these intersections existed with the conflict counts of Groups 1 and 2.

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

The process of adding, deleting, and replacing variables continued until the best model was found. The final model classification and equations for Washington, D.C. are given in Tables 8 and 9. By introducing type of traffic control and pedestrian violations, the model produced the best accuracy, 83 percent.

To use the three-group model given in Table 7, substitute the respective raw data into each equation in Table 9. The largest value indicates the proper group classification. Discriminate equations *do not* predict actual accident frequency because the dependent variable coefficients are not slope values (as produced in regression modeling). In addition, the signs of the coefficients *do not* indicate the relationship (positive or negative) between the dependent variable and the accident group number. However, the coefficients define a variable's magnitude in describing its particular group.

From the analysis procedure, the best groupings for the Seattle data were produced using pedestrian and vehicle volumes, conflicts, and number of lanes. Refer to Table 10 and the following table, which gives equations for the model based on conflicts, number of lanes, and pedestrian and vehicle volumes for Seattle

$$\text{Group 1: } G1 = 0.0943C + 0.0023P - 0.0047V + 1.6625L - 9.4869$$

$$\text{Group 2: } G2 = 0.0533C + 0.0058P - 0.0065V + 2.0950L - 14.0488$$

$$\text{Group 3: } G3 = 0.0675C + 0.0155P - 0.0058V + 2.4968L - 27.3187$$

where

L = number of lanes.

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

The final two-group models developed by use of the three-

TABLE 4 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 5 PEDESTRIAN/VEHICLE DATA AND VARIABLES FOR SEATTLE

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
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	36	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

TABLE 6 CLASSIFICATION MATRIX BASED ON THE VARIABLES OF PEDESTRIAN AND VEHICLE VOLUMES FOR WASHINGTON, D.C.

Group*	Expected Group	Number	% Correct
	1	7	
1	2	1	70
	3	2	
	Total	10	
	1	5	
2	2	2	22
	3	2	
	Total	9	
	1	1	
3	2	0	80
	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

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	

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
```

group model procedures for Washington, D.C., and Seattle are presented in the tables below.

The following classification matrix is based on the variables of pedestrian and vehicle volumes, 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	

The following equations are for the model based on pedestrian and vehicle volumes, conflicts, type of control, and number of lanes for Washington, D.C.

$$\text{Group 1: } G1 = 0.0139C - 0.0019P - 0.0029V + 2.0773S + 0.8544L - 4.7114$$

$$\text{Group 2: } G2 = 0.0475C - 0.0045P - 0.0038V + 0.6226S + 1.1048L - 6.9865$$

The following classification matrix is based on the variables of pedestrian and vehicle volumes, conflicts, and number of lanes for Seattle.

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

The following equations are for the model based on pedestrian and vehicle volumes, conflicts, and number of lanes for Seattle.

$$\text{Group 1: } G1 = 0.0934C - 0.0013P - 0.0052V + 1.5888L - 8.5028$$

$$\text{Group 2: } G2 = 0.0505C + 0.0024P - 0.0070V + 2.0441L - 13.4090$$

The Washington, D.C. model produced a 75 percent accuracy whereas Seattle model's accuracy was 83 percent.

CONCLUSIONS AND RECOMMENDATIONS

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

Because of the limited amount of accident data for Group 3 (accidents at three or more intersections), with only five such intersections in Washington, D.C., and only two in Seattle, the models from both cities were reduced to two groups: Group 1, zero-accident intersections, and Group 2, accidents at one or more intersections. Basically, the two-group model predicts an intersection's potential for having or not having an accident. The three- and two-group models are presented in Table 11.

In both cities it was evident that pedestrian and vehicle volumes and pedestrian/vehicle conflicts were the primary variables in defining pedestrian/vehicle accident occurrences. In contrast, neither the pedestrian volume and vehicle volume product ($P \times V$) nor that product divided by the percentage of turning vehicle volume [$(P \times V)/\%T$], measures that represent both pedestrian and vehicle volumes and potential conflicts, performed well in the modeling analysis. These two exposure measures may not represent, in one aspect, the true value of their product. For example, there may exist 20 pedestrians and 20 vehicles at a given location in a given time frame. Their $P \times V$ product is 400 pedestrian–vehicles, which indicates 400 potential conflict events. There may also exist a location with 2 pedestrians and 200 vehicles. Again the $P \times$

TABLE 10 CLASSIFICATION MATRIX BASED ON THE VARIABLES OF CONFLICTS, NUMBER OF LANES, AND PEDESTRIAN AND VEHICLE VOLUMES FOR SEATTLE

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 3- AND 2-GROUP MODELS FOR WASHINGTON, D.C. AND SEATTLE

Washington, DC 3-group model

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

Seattle, WA 3-group model

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

Washington, DC 2-group model

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

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

Seattle, WA 2-group model

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

where,

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

V product indicates a 400 conflict potential, but obviously 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, whereas the conflicts defined their actual accident potential interaction, not their maximum conflict potential.

The use of type of traffic control as a variable was also an indicator of pedestrian and vehicle activity. A stop-control intersection usually indicates low pedestrian and vehicle volumes whereas a signalized intersection usually indicates either high pedestrian or high vehicle activity or both. 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 whereas the Seattle models did not. Because of the pedestrian and vehicle volume differences between the two cities, the use of the traffic control variable 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 with the signalized intersections. In Seattle, however, several stop-control intersections had high pedestrian volumes and moderate vehicle volumes when compared with the signalized intersections. Thus, type of control was not distinctive when compared with pedestrian and vehicle volumes.

The Seattle three- and two-group models and the Washington, D.C., two-group model contained number of lanes as a variable. 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 defined as the number of places where the pedestrian and vehicle can interact. These places are in the travel lanes. 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. In Washington, D.C., where numerous pedestrian violations occurred, the violations were found to be indicators of accident groupings; however, 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 or not cross inside of 50 ft of the intersection in Seattle but because of lower vehicle volumes, a car may not be near the area. However, Washington, D.C., pedestrian and vehicle volumes were greater in magnitude, and a violation by a pedestrian may have been more meaningful in defining accidents.

Finally, vehicle violations were not useful in defining accident groupings. Vehicle violations of running a red signal or stopping in the crosswalk would not endanger a pedestrian if 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 (i.e., true conflicts).

Research is recommended to investigate pedestrian and vehicle violation variables that define the types of violations that lead to true conflicts. Variables of this type may better aid in defining accident occurrences because some violations rarely endanger the pedestrian.

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

In conclusion, developing a pedestrian/vehicle accident-prediction model using pedestrian and vehicle volumes and conflicts shows promise. With additional research, the relationship between pedestrian accidents and conflicts and various variables would better refine an accident prediction model in order to identify potential pedestrian accident intersections.

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