# Predicting Traffic Accidents from Roadway Elements on Urban Extensions of State Highways

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The investigation described in this report represents research by the Oregon State Highway Department to develop equations which can be used to predict accidents on the urban extensions of the State Highway System from roadway elements such as ADT, commercial and residential units and driveways, intersections, signalized intersections, indicated speed, pavement width, effective lane width, and the number of lanes.

The study utilized a sample of 426 sections with a total length of 186.4 mi. Data were analyzed by subgrouping the sections by number of traffic lanes and ADT groupings. Within these groups additional subgroups of urban extensions were studied for suburban, corporate, business, residential and mixed culture sections. The analysis used multiple correlation techniques with the end result of the analysis being a series of equations which indicated the relationships of the various roadway elements to accident rates on urban and subgroups of urban extensions of highways in Oregon.

The more important conclusions which can be drawn from the study are as follows:

1. Motor vehicle accident rates are related to certain physical features of urban extensions of the highway system. This relationship is strong enough in the higher ADT ranges to make it possible to predict accident rates with a reasonable degree of accuracy on the basis of known physical features.
2. Accident rates on low volume roads do not have a strong relationship with any roadway feature.
3. Motor vehicle accident rates increase when: (a) The number of commercial units adjacent to the section increases. (b) The number of traffic signals increases. (c) The number of intersections increases. (d) The indicated speed decreases. (e) The average daily traffic increases. (f) The pavement width increases.

THE CHANGES in recent years of highway construction to higher design standards requiring many miles of expressways and freeways have emphasized the deficiency of benefit studies used as an aid in selecting one of two or more alternate routes between common termini. Present methods of analysis provide a means for converting to monetary values benefits derived through savings in time, distances traveled, and other operating costs. However, no measure has been used for the increased safety from reduction in accidents resulting from access control and elimination of crossings at grade. Proper evaluation of benefits from expressways and freeways should include the benefits derived from the reduction in motor vehicle accidents.

The first step necessary to convert the reduction in accidents to a monetary value is a reasonable estimate of the number of accidents which will occur on both the proposed improvement and the old obsolete highway. This study was undertaken to determine if some means could be developed for predicting the number of accidents which could be expected on a given section of urban or suburban section of highway from information readily available.

A previous study, "Predicting Traffic Accidents from Roadway Elements - Rural Two-Lane Highways with Gravel Shoulders,"[1] developed a procedure for predicting accidents with reasonable accuracy for rural 2-lane highways with gravel shoulders. The characteristics of urban extensions of the state highway system from the standpoint of both design and roadside culture adjacent to the highways are quite different from rural highways. It was, therefore, felt that the formulas developed for rural highways could not be applied to urban sections. For this reason, a separate study was conducted for the urban extensions of the highway system.

In the use of accident prediction formulas for determination of motor vehicle user benefits, it is desirable to limit the roadway elements used in the prediction to those which can be readily determined. To this end the field data were confined to those that were readily available. Roadway elements which were considered, and for which data were obtained in the field, include the number of commercial units, commercial driveways, residential units, residential driveways, intersections, channelized intersections and traffic signals, the indicated speed, the pavement width, width of each shoulder, and number of traffic lanes.

Field data were obtained for 466 urban sections of highways. Of these, 426 sections permitted parallel parking on both sides, and the remaining 40 sections were distributed among those having no parking, angle parking, and various combinations of parking. To provide the maximum uniformity of sections, the study was confined to the 426 sections permitting parallel parking. The remaining 40 sections did not provide a large enough sample for a separate analysis. Because of the variable nature of the roadside culture and roadway elements on the urban sections of highways, it was not feasible to select sections of uniform length for this study. The sections varied in length from those as short as $\frac{1}{10}$ mile up to sections 2.1 miles long. The 426 sections had a total length of 186.4 miles or an average length of 0.4 mile per section.

The data were analyzed on several different breakdowns. The anticipated accident experience on 2- and 4-lane highways should be quite different. It was, therefore, considered necessary to initially consider the urban sections separately for 2- and 4-lane highways. The previous study in rural areas showed that the most reliable prediction equations were developed with a breakdown of sections into various traffic volume groupings. This then became the second major grouping in this analysis.

Prediction equations were developed for the urban sections based on the foregoing subgrouping. To further increase the accuracy of the prediction equations, the sections were subdivided between corporate and suburban sections. During the collection of the field data each section was classified by its cultural composition as residential, business, or mixed. These classifications were used for an additional subgrouping of the urban sections.

The data were analyzed by statistical methods to determine the quantitative relationship between accidents and the various roadway elements. The prediction equations were developed from multiple regression techniques. It is possible that more refined data may greatly improve the accuracy of prediction equations, however, such refinement was not deemed desirable for this particular study. The data used in the study were based on an average traffic volume and accident data for 1954 and 1955. Because of the variable length of the sections, it was not desirable to use number of accidents for this analysis, therefore, they were converted to accidents per million vehicle-miles. All regression equations provide answers in terms of accidents per million vehicle-miles.

## DATA SOURCES

### Field Work

The field data were obtained on state primary and secondary urban highways, in-

[1] Bulletin 158, Highway Research Board

cluding 2- and 4-lane sections. Any section which had new construction since 1954, the first year for which accident data were used in the analysis, was eliminated.

The field examiners recorded the following information with the use of a multiple bank counter:

1. Commercial Units (CU)
2. Commercial Driveways (CDW)
3. Residential Units (RU)
4. Residential Driveways (RDW)
5. Intersections (INT)
6. Traffic Signals (SIG)
7. Channelized Intersections (CI)

All of the above data were converted to rates (that is, driveways per mile). In addition to the above rate per mile data, the following information was also obtained in the field:

1. Indicated Speed (SP)
2. Pavement Width (PA)
3. Shoulder Width (SH)
4. Number of Lanes
5. Median Width
6. Effective Lane Width (ELA)

The sections may have had curbs, gravel shoulders, or paved shoulders; however, no distinction was made in this regard except to take these factors into account in the calculation of effective lane widths. Finally, space was provided for recording codes for urban, suburban, and culture type—that is, business, residential, or mixed, and a parking code.

A detailed description of the field procedure, along with a sample field sheet appears in Appendix A.

## Traffic Volume Data

The average daily traffic (ADT) was taken from the Traffic Volume Tables for 1954 and 1955.[2] The average for the 2 years was used in the study. As indicated earlier, traffic accident predictions are better if the data are grouped by ADT ranges. For this study arbitrary ADT ranges were used as follows: on 2-lane sections 5,000 and under, 5,000 - 9,999, and 10,000 and over. The corresponding ranges for 4-lane sections were less than 9,000, 9,000 - 17,999, and 18,000 and over.

Although it is probable that the volume of traffic on cross streets and driveways might be closely related to the accident experience on corporate and suburban sections, complete information on these traffic volumes was not available and therefore could not be included in the report.

## Accident Data

The accident data used in this study were available in the Accident Analysis Section of the Traffic Engineering Division, Oregon State Highway Department. The accident records for the years 1954 and 1955 were employed.[3]

The lack of uniform section lengths did not permit direct comparison of the various sections based on the total number of accidents on each section. It was therefore necessary to adjust each section for this difference in section length. Because of the relatively high relationships between accidents and average daily traffic, it was decided to convert the accidents for each section to accidents per million vehicle-miles, which provided the measure for direct comparison of accident experience on each section.

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[2] Oregon State Highway Department Technical Report No. 55-1 and 56-1, respectively.
[3] Oregon State Highway Department Technical Report No. 55-2 and 56-2, respectively.

## ANALYSIS

Previous study on rural sections indicated that considerable advantage could be gained by developing accident prediction equations for subgroups of the study sections. Several arrangements of subgroups were studied to obtain the best results possible. No attempt will be made here to describe the statistical techniques used in the analysis of the data, however, a description of these statistical techniques will be found in Appendix C.

The first step in the analysis was to group the data by 2- and 4-lane sections. Within these major groups subgroups were made for the selected ADT ranges. Additional subgroupings were made by studying separately corporate and suburban sections. Suburban sections were defined as those sections which were outside the coporate limits of the city, but which had an indicated speed posted. Although it was realized that this definition would have some shortcomings inasmuch as the corporate limits do not normally correspond with a change in roadside culture, they did lend themselves to subdividing sections which were independent of the observer's judgment.

A subgrouping of urban sections by roadside culture was also studied. During the

TABLE 1

DISTRIBUTION OF STUDY SECTIONS BY NUMBER OF LANES, ADT RANGES AND CULTURE TYPE

| ADT Range | Area of Culture | Number of Sections | Total Length of Sections (mi) | Average Length of Sections (mi) |
|---|---|---|---|---|
| | | 2 Lanes | | |
| Under 5,000 | Urban | 130 | 45.2 | 0.3 |
| | Suburban | 35 | 17.6 | 0.5 |
| | Corporate | 95 | 27.6 | 0.3 |
| | Business | 30 | - | - |
| | Residential | 46 | - | - |
| | Mixed | 54 | - | - |
| 5,000 - 9,999 | Urban | 140 | 54.8 | 0.4 |
| | Suburban | 33 | 18.8 | 0.6 |
| | Corporate | 107 | 36.0 | 0.3 |
| | Business | 52 | - | - |
| | Residential | 33 | - | - |
| | Mixed | 55 | - | - |
| 10,000 and over | Urban | 26 | 18.6 | 0.7 |
| | Suburban | 2 | 1.1 | 0.5 |
| | Corporate | 24 | 17.5 | 0.7 |
| | Business | 11 | - | - |
| | Residential | 5 | - | - |
| | Mixed | 10 | - | - |
| All | Corporate Portland | 22 | 15.8 | 0.7 |
| | Corporate Non-Portland | 204 | 66.0 | 0.3 |
| | | 4 Lanes | | |
| Under 9,000 | Urban | 54 | 16.4 | 0.3 |
| | Suburban | 9 | 3.7 | 0.4 |
| | Corporate | 45 | 12.7 | 0.3 |
| | Business | 35 | - | - |
| | Residential | 8 | - | - |
| | Mixed | 11 | - | - |
| 9,000 - 17,999 | Urban | 50 | 31.2 | 0.6 |
| | Suburban | 17 | 12.2 | 0.7 |
| | Corporate | 33 | 19.0 | 0.6 |
| | Business | 29 | - | - |
| | Residential | 3 | - | - |
| | Mixed | 18 | - | - |
| 18,000 and over | Urban | 26 | 20.0 | 0.8 |
| | Suburban | 5 | 2.8 | 0.6 |
| | Corporate | 21 | 17.2 | 0.8 |
| | Business | 20 | - | - |
| | Residential | 3 | - | - |
| | Mixed | 3 | - | - |
| All | Corporate Portland | 32 | 25.6 | 0.8 |
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| | Suburban | 35 | 17.6 | 0.5 |
| | Corporate | 95 | 27.6 | 0.3 |
| | Business | 30 | - | - |
| | Residential | 46 | - | - |
| | Mixed | 54 | - | - |
| 5,000 - 9,999 | Urban | 140 | 54.8 | 0.4 |
| | Suburban | 33 | 18.8 | 0.6 |
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| | Business | 52 | - | - |
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| | Mixed | 55 | - | - |
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| | Suburban | 9 | 3.7 | 0.4 |
| | Corporate | 45 | 12.7 | 0.3 |
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| | Corporate Non-Portland | 67 | 22.6 | 0.3 |

TABLE 2

ZERO ORDER CORRELATIONS BETWEEN ACCIDENT RATES AND ROADWAY ELEMENTS

| Study Group | Accident Rate - Roadway Elements Correlations | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ADT | CU | CDW | RU | RDW | INT | SIG | SP | PA | ELA |
| 2 Lane, Under 5,000 ADT | | | | | | | | | | |
| Urban | 0.03 | 0.26 | 0.13 | -0.06 | -0.14 | 0.04 | 0.06 | -0.06 | 0.37 | 0.22 |
| Suburban | 0.06 | -0.10 | -0.06 | -0.11 | -0.10 | -0.06 | [1] | 0.32 | 0.13 | 0.30 |
| Corporate | 0.03 | 0.33 | 0.20 | -0.08 | -0.15 | 0.01 | 0.04 | -0.08 | 0.37 | 0.20 |
| Business | -0.03 | 0.29 | 0.10 | -0.27 | -0.25 | -0.06 | -0.03 | -0.10 | 0.40 | 0.27 |
| Residential | 0.04 | 0.19 | 0.06 | 0.38 | -0.01 | -0.03 | 0.03 | -0.13 | 0.52 | 0.28 |
| Mixed | 0.07 | -0.03 | -0.08 | -0.03 | -0.18 | 0.16 | 0.28 | 0.11 | 0.21 | 0.00 |
| 2 Lane, 5,000 - 9,999 ADT | | | | | | | | | | |
| Urban | 0.33 | 0.66 | 0.26 | -0.15 | -0.18 | 0.45 | 0.49 | -0.32 | 0.39 | 0.19 |
| Suburban[2] | | | | | | | | | | |
| Corporate | 0.32 | 0.71 | 0.24 | [3] | [3] | 0.42 | 0.48 | -0.35 | 0.36 | 0.16 |
| 2 Lane, 10,000 and over, ADT | | | | | | | | | | |
| Urban | 0.42 | 0.67 | 0.44 | -0.07 | -0.11 | 0.53 | 0.85 | -0.44 | 0.37 | 0.02 |
| Suburban[2] | | | | | | | | | | |
| Corporate | 0.44 | 0.67 | 0.46 | [3] | [3] | 0.51 | 0.85 | -0.41 | 0.37 | 0.02 |
| 2 Lane, 5,000 and over ADT | | | | | | | | | | |
| Suburban | 0.10 | 0.15 | 0.41 | 0.04 | 0.05 | 0.52 | [1] | -0.02 | 0.16 | 0.28 |
| Business | 0.47 | 0.67 | 0.13 | 0.07 | 0.06 | 0.55 | 0.78 | -0.39 | 0.43 | 0.13 |
| Residential | 0.45 | 0.02 | -0.09 | 0.32 | 0.15 | 0.27 | 0.01 | 0.08 | 0.10 | -0.02 |
| Mixed | 0.49 | 0.46 | 0.23 | 0.33 | 0.22 | 0.64 | 0.27 | -0.20 | 0.42 | 0.09 |
| 2 Lane, All ADT's | | | | | | | | | | |
| Corporate Portland | 0.54 | 0.68 | 0.60 | [3] | [3] | 0.53 | 0.87 | -0.39 | 0.25 | -0.17 |
| Corporate Non-Portland | 0.10 | 0.47 | 0.21 | -0.08 | -0.16 | 0.16 | 0.27 | -0.20 | 0.37 | 0.22 |
| 4 Lane, Under 9,000 ADT | | | | | | | | | | |
| Urban | 0.05 | 0.39 | 0.20 | -0.13 | 0.04 | 0.13 | 0.79 | -0.11 | 0.07 | -0.18 |
| Suburban[2] | | | | | | | | | | |
| Corporate | 0.14 | 0.42 | 0.29 | -0.17 | 0.03 | 0.11 | 0.80 | -0.06 | -0.08 | -0.21 |
| Business | 0.03 | 0.35 | 0.12 | 0.12 | 0.28 | 0.12 | 0.81 | -0.08 | 0.03 | -0.23 |
| Residential & Mixed | 0.07 | -0.11 | 0.01 | -0.20 | 0.26 | -0.04 | 0.56 | 0.20 | 0.20 | -0.05 |
| 4 Lane, 9,000 - 17,999 ADT | | | | | | | | | | |
| Urban | 0.27 | 0.62 | 0.30 | 0.09 | -0.02 | -0.39 | 0.78 | -0.45 | 0.36 | 0.05 |
| Suburban[2] | | | | | | | | | | |
| Corporate | 0.24 | 0.59 | 0.18 | [3] | [3] | 0.17 | 0.76 | -0.41 | 0.25 | 0.04 |
| 4 Lane 18,000 & over ADT | | | | | | | | | | |
| Urban | 0.69 | 0.66 | 0.29 | 0.27 | 0.18 | 0.51 | 0.71 | -0.72 | 0.57 | 0.49 |
| Suburban[2] | | | | | | | | | | |
| Corporate | 0.64 | 0.60 | 0.20 | [3] | [3] | 0.33 | 0.72 | -0.72 | 0.49 | 0.50 |
| 4 Lane, 9,000 & over ADT | | | | | | | | | | |
| Business | 0.49 | 0.66 | 0.14 | 0.11 | -0.10 | 0.39 | 0.79 | -0.56 | 0.35 | 0.14 |
| Residential & Mixed | 0.67 | 0.49 | 0.34 | 0.37 | 0.19 | 0.51 | 0.74 | -0.36 | 0.68 | 0.07 |
| 4 Lane, All ADT's | | | | | | | | | | |
| Suburban | -0.02 | 0.36 | 0.09 | 0.37 | 0.22 | 0.69 | 0.62 | -0.36 | 0.52 | 0.17 |
| Corporate Portland | 0.64 | 0.58 | 0.29 | [3] | [3] | 0.27 | 0.78 | -0.46 | 0.48 | 0.44 |
| Corporate Non-Portland | 0.19 | 0.47 | 0.23 | -0.17 | -0.01 | 0.12 | 0.71 | -0.17 | -0.07 | -0.18 |

Note Roadway elements considered for regression equations are underlined

[1] Insufficient sample to compute simple correlation

[2] Insufficient sample sections for computation of reliable regression equations. Data combine with other ADT ranges

[3] Preliminary analysis indicated low correlations, therefore, computations were not completed.

field analysis, each section was classified by the roadside culture—that is, business, residential, or mixed, with the distinction being that if the roadside culture was composed of 75 percent business establishments it was typed business, and if the roadside culture was 75 percent residential it was typed residential. Sections with mixed culture were typed mixed.

A final subgrouping of the corporate sections was made to determine if the large Portland Metropolitan Area had characteristics which would make prediction in that area more reliable than predictions in the other corporate areas of the state.

A distribution of the study sections by number of lanes, ADT ranges, and area or culture type is shown in Table 1. Also shown in this table are the total lengths of the sections and average lengths of the sections for urban groupings, suburban and corporate groupings. In the analysis of the data, it was decided that any group with less than 20 sections would not provide an adequate sample to develop reliable regression equations. A review of this table indicates that there were only two suburban 2-lane sections with an ADT of 10,000 and over. This did not provide an adequate sample for computation for regression equations; therefore, they were combined with the next lower ADT group in the analysis. A similar procedure was used for other groupings which had inadequate samples.

The first step in the statistical analysis was to compute the zero order correlation coefficient between accident rates and each of the roadside elements. The results of these computations are shown in Table 2. In examining this table, a positive correlation indicates that accident rates increase with an increase in the roadway elements, whereas the negative correlation indicates that accident rates increase with a decrease in roadway elements. Perfect correlation between the factors would be indicated by a value of one, and no correlation would be indicated by a value of zero.

The ADT had, with two exceptions, a positive correlation with accident rates. This relationship varies from practically no correlation to fairly good correlation. It will be observed that the subgroupings, corporate, suburban, business, residential, and mixed, do not make any substantial change in the correlation between accident rates and the average daily traffic. The correlation between accident rates and ADT increased for both 2- and 4-lane sections for the higher ADT groups, with generally higher correlations for all groupings of 4-lane sections.

The number of commercial units per mile, with three exceptions, was positively correlated with accident rates. Here again, the correlations for subgroupings do not materially better the correlation of urban sections. This roadway element had some fairly good correlations with accident rates, and as a result was used more frequently than any other element in the development of regression equations.

The number of commercial driveways was generally positively correlated with accident rates. Although fairly good correlations were found, it will be noted that commercial driveways were not as highly correlated with accident rates as the number of commercial units.

The number of residential units per mile, similarly, was evenly divided between positive and negative correlations. With four exceptions the correlations were low and could not be used for the development of regression equations. Residential units were used only in some regression equations for the subgroupings suburban, residential, or mixed culture. In a few instances preliminary investigation indicated that very low correlations would be obtained; therefore, the correlation with accident rates was not computed.

The number of residential driveways per mile had in all cases a very low correlation with accident rates, and did not in any grouping have a high enough correlation so that it could be considered in developing regression equations. This element was the worst predictor of accident rates of any studied.

TABLE 3

ZERO ORDER CORRELATIONS BETWEEN ACCIDENT RATES AND ROADWAY ELEMENTS
(Weighted for Length)

| | Accidents - Roadway Elements Correlations | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Study Group | ADT | CU | CDW | RU | RDW | INT | SIG | SP | PA | ELA |
| 2 Lane, Under 5,000 ADT | | | | | | | | | | |
| Suburban | 0 01 | -0. 20 | -0. 22 | -0. 24 | -0 19 | -0 01 | [1] | 0 41 | 0. 43 | 0 49 |
| Corporate | -0 14 | 0 18 | 0 15 | [2] | [2] | 0 07 | 0 04 | -0 08 | 0. 27 | 0 03 |
| 2 Lane, 5,000 - 9,999 ADT | | | | | | | | | | |
| Corporate | 0 35 | 0. 77 | 0 34 | [2] | [2] | 0. 44 | 0. 59 | -0 32 | 0. 46 | 0 22 |
| 2 Lane, 10,000 & over ADT | | | | | | | | | | |
| Corporate | 0 32 | 0. 76 | 0 50 | [2] | [2] | 0. 66 | 0. 89 | -0 64 | 0. 62 | 0. 17 |
| 2 Lane, 5,000 & over ADT | | | | | | | | | | |
| Suburban | 0. 08 | 0 26 | 0. 41 | 0. 09 | 0. 08 | 0. 66 | 0. 34 | -0 07 | 0 22 | 0. 38 |
| 2 Lane, All ADT's | | | | | | | | | | |
| Corporate Portland | 0 29 | 0 68 | 0. 42 | [2] | [2] | 0 60 | 0. 86 | -0. 55 | 0 36 | -0. 20 |
| Corporate Non-Portland | 0 09 | 0 46 | 0. 26 | [2] | [2] | 0 24 | 0 38 | -0. 24 | 0. 39 | 0 19 |
| 4 Lane, Under 9,000 ADT | | | | | | | | | | |
| Corporate | 0 05 | 0. 63 | 0 20 | -0 13 | 0 05 | 0 12 | 0 70 | -0 34 | -0 12 | -0 36 |
| 4 Lane, 9,000 - 17,999 ADT | | | | | | | | | | |
| Corporate | 0. 34 | 0. 71 | 0 38 | [2] | [2] | 0. 47 | 0. 82 | -0 58 | 0. 32 | 0 03 |
| 4 Lane, 18,000 & over ADT | | | | | | | | | | |
| Corporate | 0. 54 | 0. 71 | 0. 53 | [2] | [2] | 0 52 | 0. 79 | -0. 73 | 0. 52 | 0. 30 |
| 4 Lane, All ADT's | | | | | | | | | | |
| Suburban | -0. 08 | 0. 37 | 0 07 | 0. 62 | 0 52 | 0 67 | 0 48 | -0 48 | 0. 64 | 0. 19 |
| Corporate Portland | 0. 48 | 0 71 | 0 54 | [2] | [2] | 0 54 | 0. 81 | -0 63 | 0 54 | 0 30 |
| Corporate Non-Portland | -0. 29 | 0. 31 | 0 18 | [2] | [2] | 0 08 | 0. 34 | -0 18 | -0 13 | -0 38 |

Note Roadway elements considered for regression equations are underlined
[1] Insufficient sample to compute simple correlation
[2] Insufficient sample sections for computation of reliable regression equations. Data combine with other ADT ranges.

TABLE 4

MULTIPLE CORRELATIONS BETWEEN ROADWAY ELEMENTS AND ACCIDENT RATES

| Study Group | Best Predictors | Coefficient of Multiple Correlation | | Standard Error of Estimate | | Ratio of Standard Error of Estimate to the Mean | |
|---|---|---|---|---|---|---|---|
| | | Un-Weighted | Weighted | Un-Weighted | Weighted | Un-Weighted | Weighted |
| 2 Lane, Under 5,000 ADT | | | | | | | |
| Urban | [1] | [1] | [2] | [1] | [2] | [1] | [2] |
| Suburban | (RU), (SP), (ELA) | 0 37 | 0 52 | 5.26 | 8 85 | 1 57 | 1 24 |
| Corporate | CU, PA | 0 39 | [2] | 17.43 | [2] | 1 74 | [2] |
| Business | [1] | [1] | [2] | [1] | [2] | [1] | [2] |
| Residential | RU, PA | 0.55 | [2] | 6 76 | [2] | 1 11 | [2] |
| Mixed | [1] | [1] | [2] | [1] | [2] | [1] | [2] |
| 2 Lane, 5,000 - 9 999 ADT | | | | | | | |
| Urban | ADT, CU, INT, SIG, SP, PA | 0 74 | [2] | 6 44 | [2] | 0 69 | [2] |
| Suburban[3] | | | | | | | |
| Corporate | (ADT), (CU), (CDW), (INT), (SIG), (SP), (PA) | 0 75 | (.82 | 6 82 | 6 11 | 0 68 | 0 62 |
| 2 Lane 10,000 & over ADT | | | | | | | |
| Urban | ADT, CU, CDW, INT SIG SP | 0 89 | [2] | 8 07 | [2] | 0 42 | [2] |
| Suburban[3] | | | | | | | |
| Corporate | (ADT), CU, (CDW), (INT), (SIG), (SP), (PA) | 0 89 | 0 93 | 7 98 | 5 44 | 0.39 | 0.34 |
| 2 Lane, 5,000 & over ADT | | | | | | | |
| Suburban | (CDW), (INT), (SIG), (ELA) | 0 66 | 0 75 | 3 58 | 2 95 | 0.56 | 0.44 |
| Business | ADT, CU. INT, SIG, SP, PA | 0.86 | [2] | 8 25 | [2] | 0.53 | [2] |
| Residential | ADT, RU | 0 49 | [2] | 4 56 | [2] | 0 64 | [2] |
| Mixed | ADT, CU, RU, INT, PA | 0 69 | [2] | 5 25 | [2] | 0.62 | [2] |
| 2 Lane, All ADT's | | | | | | | |
| Corporate Portland | (ADT), (CU), (CDW), (INT), (SIG), (SP), (PA) | 0.92 | 0 91 | 7.05 | 5 48 | 0 37 | 0 36 |
| Corporate Non-Portland | (CU), PA | 0.48 | 0 46 | 13.23 | 14 28 | 1 29 | 1 38 |
| 4 Lane, Under 9,000 ADT | | | | | | | |
| Urban | CU, SIG | 0 84 | [2] | 7 75 | [2] | 0 59 | [2] |
| Suburban[3] | | | | | | | |
| Corporate | (CU), (SIG), (SP), (ELA) | 0 86 | 0 80 | 7 67 | 8 17 | 0 57 | 0 49 |
| Business | CU, SIG | 0 86 | | 8 46 | [2] | 0 55 | [2] |
| Residential & Mixed | [1] | [1] | | [1] | [2] | [1] | [2] |
| 4 lane, 9,000 - 17,999 ADT | | | | | | | |
| Urban | CU, INT, SIG, SP, PA | 0 81 | [2] | 5 95 | [2] | 0 42 | [2] |
| Suburban[3] | | | | | | | |
| Corporate | (ADT), (CU), (CDW), (INT), (SIG), (SP) | 0 78 | 0 88 | 6 40 | 4 55 | 0 40 | 0.28 |
| 4 Lane, 18,000 & over ADT | | | | | | | |
| Urban | ADT, CU, INT, SIG, SP, PA | 0 89 | [2] | 6 30 | [2] | 0 29 | [2] |
| Suburban[3] | | | | | | | |
| Corporate | (ADT), (CU), (CDW), (INT), (SIG), (SP), (PA) | 0 88 | 0 92 | 6 20 | 5 33 | 0 25 | 0 25 |
| 4 Lane, 9,000 & over ADT | | | | | | | |
| Business | ADT, CU, INT, SIG, SP, PA | 0.87 | [2] | 6 30 | [2] | 0 33 | [2] |
| Residential & Mixed | ADT, CU, INT, SIG, PA | 0 86 | [2] | 4 78 | [2] | 0 35 | [2] |
| 4 Lane, All ADT's | | | | | | | |
| Suburban | (CU), RU, (RDW), (INT), (SIG), (SP), (PA) | 0 90 | 0 88 | 3 56 | 3 40 | 0 34 | 0 33 |
| Corporate Portland | (ADT), (CU), (CDW), (INT), (SIG), (SP), (PA) | 0 84 | 0 90 | 7 37 | 5 28 | 0.36 | 0.28 |
| Corporate Non-Portland | (ADT), (CU), (SIG), (ELA) | 0 74 | 0 58 | 9 33 | 31 92 | 0 63 | 1.40 |

Note. Best predictors underlined for unweighted, parenthesis for weighted.

[1] No prediction equations computed because the zero order correlations indicated insignificant correlations

[2] No prediction equations computed

[3] Insufficient sample sections for computation of reliable regression equations

The number of intersections per mile was normally positively correlated with accident rates. Here again subgrouping of urban sections did not materially improve the correlations. Fairly good correlations were found for some subgroups, and this element was used frequently in the development of the regression equations.

The number of traffic signals per mile was with one exception always positively correlated with accident rates. This element had one of the highest correlations with accident rates of any of the elements considered, and was exceeded only by commercial units in the number of groups in which it was used for computation of regression equations. This element again did not show appreciable increase in correlations for the subgroups of the urban sections. In general, correlations for 4-lane sections were much higher than for 2-lane sections. This is probably accounted for, in part, by the traffic volume warrant used for determining the need for traffic signals. Although this element had one of the highest correlations with accident rates, it also had more variability than the other elements, and for this reason it was not one of the most reliable predictors of accident rates. In a number of subgroups there was an insuficient number of traffic signals for the computation of the zero order correlation.

The indicated speed as posted in the field showed in most subgroups a negative relationship with accident rates. The relationship was good enough in about one-half of the cases for inclusion in the regression equations. It appears from these correlations that increasing speed had a tendency to decrease the accident rates. However, the practice in Oregon has been, in part at least, to establish speed zones and post reduced indicated maximum speeds in those sections which have an abnormal accident experience. This procedure undoubtedly was responsible in a large part for the negative correlations obtained in that fewer adjustments for speed zones were established in sections with a relatively low accident rate, whereas sections of high accident rates were posted for reduced speeds.

The pavement width showed positive relationship with accident rates. However, the relationship varies considerably and was normally fairly low. Pavement width was included in several of the regression equation.

The effective lane width was generally positively correlated; however, there were frequent negative correlations. The correlation of this element was very small, and therefore this element was infrequently included in the regression equations.

The variable lengths of study sections indicated that a bias could be present in the analysis by giving undue consideration to short sections and insufficient consideration to relatively long sections. Therefore, a separate analysis was made on the suburban and corporate subgroups to test the presence of a length bias. For this analysis each study section was divided into a series of sections $\frac{1}{10}$ mile long. The roadway elements

TABLE 5

REGRESSION EQUATIONS, ACCIDENT RATES FROM ROADWAY ELEMENTS

| Study Group | Regression Equations |
|---|---|
| 2 Lane, Under 5,000 ADT | |
| Urban | [1] |
| Suburban | A = -9.67 + 0.14 SP + 0.73 ELA |
| Corporate | A = -6.28 + 0.08 CU + 0.50 PA |
| Business | [1] |
| Residential | A = -8.56 + 0.05 RU + 0 48 PA |
| Mixed | [1] |
| 2 Lane, 5,000 - 9,999 ADT | |
| Urban | A = -7 54 + 0.09 ADT + 0.12 CU + 0.36 INT + 0 94 SIG + 0 06 SP - 0.01 PA |
| Suburban | [2] |
| Corporate | A = -4.44 + 0 09 ADT + 0 15 CU + 0 26 INT + 0.72 SIG + 0.02 SP - 0.08 PA |
| 2 Lane, 10,000 and over ADT | |
| Urban | A = -18.21 + 0 09 ADT + 0.25 CU + 0.07 CDW + 0.41 INT + 3.87 SIG - 0 16 SP |
| Suburban | [2] |
| Corporate | A = -1 01 + 0.04 ADT + 0.02 CU + 0.12 CDW + 0.38 INT + 3.98 Sig - 0.15 SP |
| 2 Lane, 5,000 and over ADT | |
| Suburban | A = -4.42 + 0.09 CDW + 0.57 INT + 0 29 ELA |
| Business | A = -2.66 + 0.10 ADT + 0.11 CU + 0.10 INT + 2.66 SIG - 0.16 SP + 0 05 PA |
| Residential | A = -2.18 + 0.11 ADT + 0.03 RU |
| Mixed | A = -5 88 + 0.05 ADT + 0.01 CU + 0 03 RU + 0.64 INT + 0.08 PA |
| 2 Lane, all ADT's | |
| Corporate Portland | A = 13.45 - 0.03 ADT + 0.11 CU + 0.66 CDW - 0.33 INT + 4.27 SIG - 0 12 SP |
| Corporate Non-Portland | A = -1 10 + 0 14 CU + 0.19 PA |
| 4 Lanes, Under 9,000 ADT | |
| Urban | A = 4 60 + 0.07 CU + 6 78 SIG |
| Suburban | [2] |
| Corporate | A = 3.04 + 0.08 CU + 6 78 SIG |
| Business | A = 2.61 + 0.08 CU + 6.88 SIG |
| Residential and Mixed | [1] |
| 4 Lanes, 9,000 - 17,999 ADT | |
| Urban | A = 7.93 + 0 04 CU + 0.03 INT + 2 70 SIG - 0 10 SP + 0.05 PA |
| Suburban | [2] |
| Corporate | A = 7.89 + 0.04 CU + 2.47 SIG |
| 4 Lanes, 18,000 and over ADT | |
| Urban | A = 1.79 + 0.18 ADT + 0.04 CU + 0.23 INT + 0.80 SIG - 0 70 SP - 0.09 PA |
| Suburban | [2] |
| Corporate | A = 33.57 + 0.14 ADT + 0.03 CU + 1.42 SIG - 0.94 SP - 0 32 PA |
| 4 Lanes, 9,000 and over ADT | |
| Business | A = 37.19 + 0 04 ADT + 0.05 CU - 0 16 INT + 2.11 SIG - 0.40 SP - 0 35 PA |
| Residential and Mixed | A = -11 26 + 0 07 ADT + 0.16 CU + 0.09 INT + 2.19 SIG + 0.35 PA |
| 4 Lanes, all ADT's | |
| Suburban | A = -26.97 + 0 04 CU + 0.04 RU + 0.32 INT + 2.88 SIG + 0 07 SP + 0.54 PA |
| Corporate Portland | A = 5.65 + 0.06 ADT + 0.08 CU + 2.44 SIG + 0.20 SP - 0.31 PA |
| Corporate Non-Portland | A = 6 55 + 0.06 CU + 3.80 SIG |

[1] No prediction equations computed because the zero order correlations indicated insignificant correlations

[2] No prediction equations computed.

TABLE 6

REGRESSION EQUATIONS, ACCIDENT RATES FROM ROADWAY ELEMENTS
(Weighted for Length)

| Study Group | Regression Equations |
|---|---|
| 2 Lane, Under 5,000 ADT | |
| Suburban | A = -29.98 + 0 01 RU + 0 23 SP + 2.37 ELA |
| Corporate | [1] |
| 2 Lanes, 5,000 - 9,999 ADT | |
| Urban | A = -3 40 + 0 05 ADT + 0 20 CU - 0.07 CDW + 0.32 INT + 1 09 SIG + 0 12 SP - 0.12 PA |
| 2 Lanes, 10,000 and over ADT | |
| Urban | A = 3.76 - 0.01 ADT + 0.11 CDW + 0 34 INT + 4.25 SIG - 0.10 SP + 0 02 PA |
| 2 Lanes, 5,000 and over ADT | |
| Suburban | A = -1.99 + 0.08 CDW + 0.68 INT + 0 94 SIG + 0.05 ELA |
| 2 Lanes, all ADT's | |
| Corporate Portland | A = 26.50 - 0.07 ADT + 0.10 CU + 0 04 CDW - 0.07 INT + 4.62 SIG - 0.13 SP - 0.26 PA |
| Corporate Non-Portland | A = 3.81 + 0 18 CU |
| 4 Lanes, Under 9,000 ADT | |
| Urban | A = 35.30 + 0.09 CU + 3.02 SIG - 0 12 SP - 3.02 ELA |
| 4 Lanes, 9,000 - 17,999 | |
| Urban | A = -1.43 + 0.05 ADT + 0.06 CU + 0.08 CDW + 0 06 INT + 2.13 SIG - 0.04 SP |
| 4 Lanes, 18,000 and over ADT | |
| Urban | A = 13.17 + 0.10 ADT - 0.03 CU = 0 25 CDW - 0 39 INT + 2.40 SIG - 0.71 SP - 0.02 PA |
| 4 Lanes, all ADT's | |
| Suburban | A = -23.06 + 0.03 CU + 0 11 RDW + 0.32 INT + 2 63 SIG + 0.04 SP + 0.48 PA |
| Corporate Portland | A = 14.05 + 0.04 ADT - 0.04 CU + 0 24 CDW - 0 09 INT + 3.07 SIG - 0 46 SP - 0 05 PA |
| Corporate Non-Portland | A = 162.34 - 0.32 ADT + 0.04 CU + 6.23 SIG - 11 27 ELA |

[1] No prediction equations computed because the zero order correlations indicated insignificant correlations.

were prorated to each of these sections of uniform length. The zero order correlations between accident rates and roadway elements for the study sections weighted for length variation are shown in Table 3.

In general, the same comments apply to this table as applied to the zero order correlations in the unweighted data. In some instances the correlations between accident rates and roadway elements were increased by the weighting process; on the other hand, there were other cases where the correlations were not as good. In general, very little benefit was realized by adjusting the study sections to compensate for the varying length of sections.

From the zero order correlations referred to in Table 2, regression equations and coefficients of multiple correlation were computed for the various groupings of urban sections. Table 4 shows the coefficients of multiple correlation, the standard error of estimate, and the ratio of the standard error of estimate to the mean for these various groupings of urban sections. In addition, information is shown for the original data and the data compensated for length variations. Also shown are the roadway elements which were the best predictors of accident rates for each of the various subgroups.

As a guide for determining which regression equations would be acceptable for use, it was arbitrarily decided that the ratio of the standard error of estimate to the mean should be no larger than 0.5. This means that two-thirds of the time the regression equations can give predicted accident rates which will be in error less than 50 percent of the mean accident rate. This appears to be quite a large allowable error. On the other hand, the nature of the data employed in the study was such that relatively large errors must be used if any usable results are to be developed.

A review of Table 4 indicates that urban groupings of the original data gave fairly reliable regression equations, except for 2-lane highways with less than 5,000 vehicles per day. For this particular group, the zero order correlations were too low to warrant development of equations.

The subgrouping of urban sections by suburban, corporate, business, residential, and mixed culture did in some cases improve the result of the regression equations. However, this slight improvement did not warrant the additional time and effort necessary to make the subdivision. A study of the results of the unweighted data and the

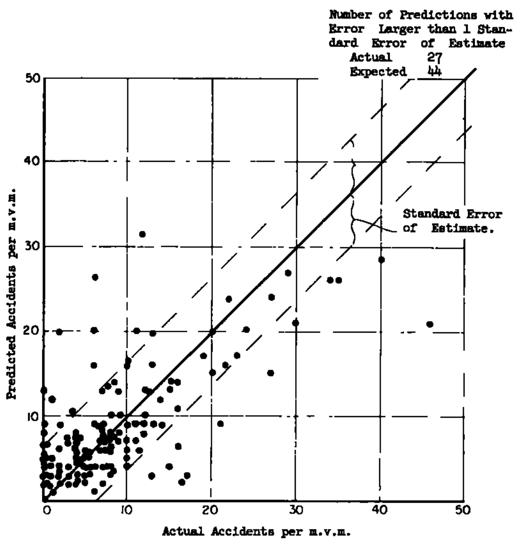


Figure 1. Comparison of predicted accident rates and actual accident rates in two-lane urban sections. (5,000 - 9,999 ADT)

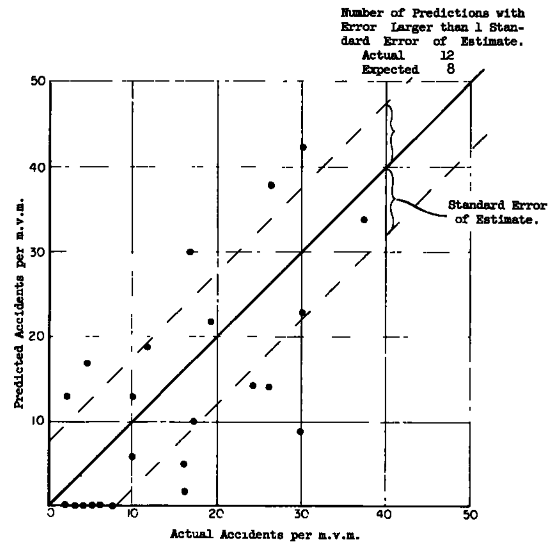


Figure 2. Comparison of predicted accident rates and actual accident rates in two-lane urban sections. (10,000 and over ADT)

weighted data indicate, in most cases, slightly better results for the weighted data than for the unweighted data. However, here again it did not appear that there was sufficient improvement to warrant the additional work required for this refinement.

Regression equations developed for the unweighted data are shown in Table 5, and the regression equations for the data weighted for length variations are shown in Table 6. In the development of these regression equations, only those elements which had

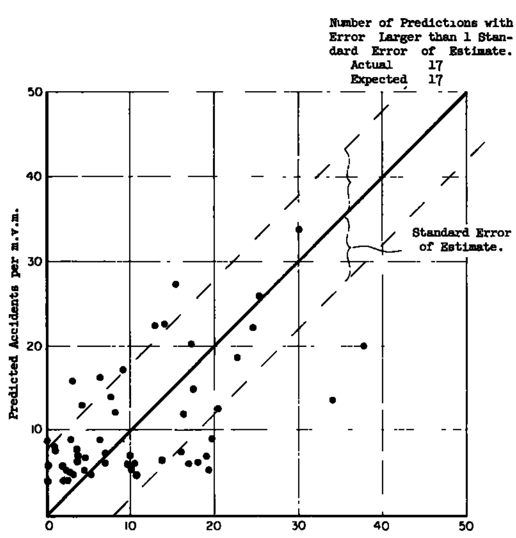


Figure 3. Comparison of predicted accident rates and actual accident rates in four-lane urban sections. (Under 9,000 ADT)

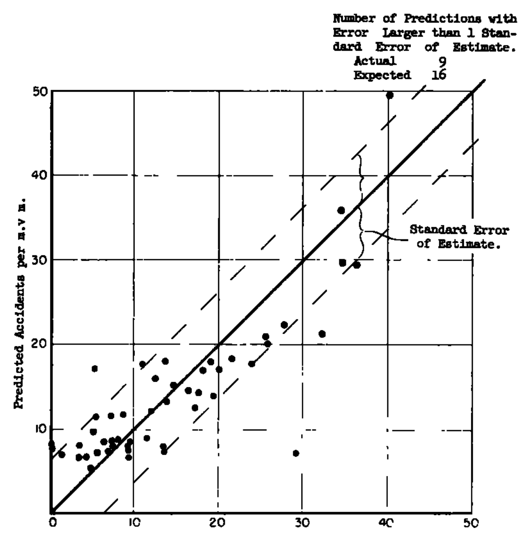


Figure 4. Comparison of predicted accident rates and actual accident rates in four-lane urban sections. (9,000 - 17,999 ADT)

zero order correlations greater than 0. 30 were considered. It will be noted in a few instances that roadway elements were indicated as being used in the development of the regression equations, however, they did not appear in the equation. This was the result of the coefficient for that element being less than 0. 005.

## COMPARISON OF PREDICTIONS WITH ACTUAL CASE HISTORIES

The regression equations developed in this study were employed to predict the accident rate which would be expected to occur on the urban sections within the various ADT groups.

Figures 1 through 5 show the comparison of predicted accident rates and actual accident rates. Also shown on the figures is the standard error of estimate for each equation. For normal distribution, 68 percent of the predictions should fall within the range of ± one standard error of estimate. For the five equations for which comparisons were made, the predicted values within the range of one standard error of estimate exceeded expectations for two of the equations, and were equal or less than expectations for the other three. The difference between the actual values within the range and the expected values was generally quite small and indicated that the theoretical standard error of estimate could be used with a reasonable degree of accuracy.

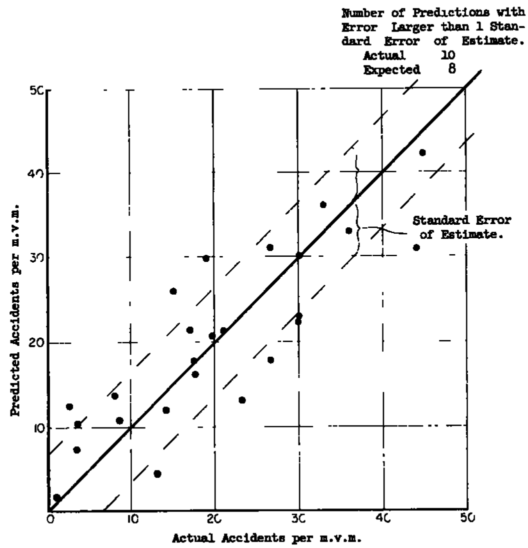


Figure 5. Comparison of predicted accident rates and actual accident rates in four-lane urban sections. (18,000 and over ADT)

## SUMMARY

1. Accident rate predictions are better for 4-lane highways than for 2-lane highways, and further are better for those sections with higher ADT.
2. Subgrouping of the urban sections by suburban, corporate, business, residential or mixed culture does not provide better predictions of motor vehicle accident rates.
3. Compensating for varying length of study sections does not provide better predictions of accident rates.
4. The most important roadway element in predicting traffic accident rates for urban sections is the number of commercial units adjacent to the section. The number of commercial units becomes a better predictor as the number of traffic lanes increases and as the average daily traffic increases.
5. The second most important roadway element in predicting traffic accident rates in the number of traffic signals which becomes a better predictor as the number of traffic lanes increases and as the average daily traffic increases.
6. Other important elements for predicting accident rates in order of importance are: the number of intersections, the indicated speed, the average daily traffic, and pavement width. Average daily traffic becomes a better predictor as the traffic volumes increase.
7. The number of commercial driveways, residential units and residential driveways, and the effective lane width are relatively unimportant roadway elements for predicting traffic accident rates. Commercial driveways can be used only for 2-lane sections. Residential driveways are of no value for predicting accident rates.
8. The following equations can be used to predict accident rates on urban sections of the state highway system:

2-Lane, 5,000 - 9,999 ADT
A = -7.54 + 0.09 ADT + 0.12 CU + 0.36 INT
+ 0.94 SIG + 0.06 SP - 0.01 PA

2-Lane, 10,000 or Over ADT
A = -18.21 + 0.09 ADT + 0.25 CU + 0.07 CDW
+ 0.41 INT + 3.87 SIG - 0.16 SP

4-Lane, Under 9,000 ADT
A = 4.60 + 0.07 CU + 6.78 SIG

4-Lane, 9,000 - 17,999 ADT
A = 7.93 + 0.04 CU + 0.03 INT + 2.70 SIG
- 0.10 SP + 0.05 PA

4-Lane, 18,000 or Over ADT
A = 1.79 + 0.18 ADT + 0.04 CU + 0.23 INT
+ 0.80 SIG - 0.70 SP - 0.09 PA

in which:

A = Accidents per million vehicle miles.
ADT = The average daily traffic divided by 100.
CU = The number of commercial units per mile.
CDW = The number of commercial driveways per mile.
INT = The number of intersections per mile.
SIG = The number of traffic signals per mile.
SP = The indicated speed.
PA = The pavement width in feet.

## CONCLUSIONS

1. Motor vehicle accident rates are related to certain physical features of urban extensions of the highway system. This relationship is strong enough in the higher ADT ranges to make it possible to predict accident rates with a reasonable degree of accuracy on the basis of known physical features.
2. Accident rates on low volume roads do not have a strong relationship with any roadway feature.
3. Motor vehicle accident rates increase when:

   a. Number of commercial units adjacent to the section increases.
   b. Number of traffic signals increases.
   c. Number of intersections increases.
   d. Indicated speed decreases.
   e. Average daily traffic increases.
   f. Pavement width increases.

# *Appendix A*

## SOURCE OF RAW DATA

The raw data employed in this study were derived from 2 major sources. The first source was obtained by field inventory, and included roadway, parking, and culture characteristics of the sections. The second source of data was obtained from office records.

### Field Data

The field workers worked in pairs, one of them driving while the other tabulated the roadway elements. Among the elements for which data were obtained were the number of commercial units and driveways, residential units and driveways, intersections, traffic signals, and channelization. Multiple bank calculators were used to facilitate this portion of the field work. In addition to the above tabulations, it was necessary to make periodic stops to measure pavement and shoulder widths each time there was an arterial change along the route.

Also recorded were the cultural classifications of each section. Three major groups were used for this—business, residential, and mixed. Based upon this criterion, if 75 percent of the buildings in the area were for business purposes it was classified as business, if 75 percent of the buildings were residential the section was classified as residential, and any combination of business and residential establishments between these two values was classified as mixed.

Information was also obtained on parking, whether it was permitted, and also the type of parking whether angle, parallel, or mixed. A sample field sheet is shown in Figure 6. The location for which the data were obtained would be indicated by the highway number appearing in the upper left-hand corner and milepost readings which were recorded in the extreme right-hand column under "Other Characteristics." The body of the table provided space for recording the following information in order: frequency

Highway No. 15

| Commercial Units (1) | Commercial Dwys. (2) | Residential Units (3) | Residential Dwys. (4) | Intersections (5) | Signals (6) | Culture (7) | Roadway Characteristic (8) | Curb or Shldr. (9) | Speed Indicated (10) | Other Characteristics and Comments (11) |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 5 | 1 | 1 | I : 4<br>C : 0 | 0 | (B)<br>R<br>M | (PP) AP NP \| (PP) AP NP<br>23' | RS : 5<br>LS : 6 | 25 | M.P. : 92.92<br>at C.L. Sisters<br>Median Wid. 0<br>M__ U__<br>M.P. : 92.73 |
| 3 | 4 | 1 | 1 | I : 1<br>C : 0 | 0 | (B)<br>R<br>M | (PP) AP NP \| (PP) AP NP<br>48' | RS : 11<br>LS : 0<br>(Curb) | 25 | M.P. : 92.73<br>50' beyond Larch<br>Median Wid. 0<br>M__ U__<br>M.P. : 92.66 |
| 17 | 7 | 3 | 2 | I : 3<br>C : 0 | 0 | (B)<br>R<br>M | (PP) AP NP \| (PP) AP NP<br>48' | RS : 0<br>(Curb)<br>LS : 0<br>(curb) | 25 | M.P. : 92.66<br>50' beyond Fir St.<br>Median Wid. 0<br>M__ U__<br>M.P. : 92.48 |
| 3 | 4 | 7 | 1 | I : 2<br>C : 0 | 0 | B<br>(R)<br>M | (PP) AP NP \| (PP) AP NP<br>44' | RS : 6<br>LS : 0<br>(curb) | 25 | M.P. : 92.48<br>50' beyond Ash St<br>Median Wid. 0<br>M__ U__<br>M.P. : 92.39 |
| 8 | 12 | 2 | 1 | I : 1<br>C : 0 | 0 | (B)<br>R<br>M | (PP) AP NP \| (PP) AP NP<br>44' | RS : 6<br>LS : 4 | 25 | M.P. : 92.39<br>50' beyond Oak St<br>Median Wid. 0<br>M__ U__<br>Pine St 0.07<br>M.P. : 92.27 |

Figure 6. Urban roadway elements study by Oregon State Highway Department.

of commercial units and commercial driveways, residential units and residential driveways.

Under the column headed "Intersections" opposite "I" were indicated the number of intersections, and opposite "C" the number of channelized intersections. Col. 6 was used for recording the number of traffic signals in the section. Col. 7 was used for the culture characteristics by circling "B" for business, "R" for residential, and "M" for mixed. Space was provided in Col. 8 for recording the lane width and type of parking. The lane width was recorded to the nearest foot just above the arrow. At the ends of the arrow appear the letters PP, AP, and NP, provided for recording of parallel parking, angle parking, and no parking, respectively, for each side of the road. In Col. 9 space was provided for recording the curb and shoulder characteristics of the particular section, with shoulder width indicated for both right and left shoulders. Zero for shoulder width was used to indicate a curve section. Col. 10 provides space for recording the posted speed for each section. Col. 11 provides space for recording the termini of each section by milepost. Space was also provided for a very brief description of the termini and to indicate median widths and, further, whether the medians were mountable or unmountable.

In addition to the field data sheets described above, the field workers carried a plat map of the city in which they were working; with a colored pencil they marked the route they traveled and indicated breaks between consecutive sections. It was necessary for the field workers to terminate a given section with any change in the field characteristics from the previous section; that is, the field workers terminated a given section if there was a change from angle to parallel parking and from parallel to no parking, or when the shoulder width changed from one section to another, or if there was a difference in culture characteristics, lane width, or indicated speed. These section breaks were necessary to obtain, to the extent possible, homogeneous characteristics of roadway elements for each section. As an example, it would be impossible to relate indicated speeds to accident rates if there were no consistent values of indicated speed for the given section.

The above paragraphs describe the data which were obtained during the field procedures. However, the data were very incomplete with regard to certain roadway elements. For example, commercial driveways and units, residential driveways and units, and intersections were recorded with regard to their absolute frequency. No attempt was made in the field to distinguish between commercial driveways which might handle as many as 500 cars per day and those that might not be used more than ten times per week. Also, with regard to commercial units and residential units, the only thing that was noted was the number of entrances facing the roadway. Thus a 4-unit apartment with 1 exit was counted as 1 residential unit, whereas a 4-unit apartment with 4 exits was counted as 4 units. The situation was often inaccurate with regard to commercial units, since a 10-story building might have only one street entrance while a one-story building might have two or more entrances. The former was counted as 1 commercial unit, whereas the latter was counted as 2 or more commercial units if it housed a separate business for each entrance.

With regard to intersections, no record was made of the type of intersection—that is whether it was a "T" or a "X" type. Furthermore, traffic volume on the side streets was not recorded nor utilized in any part of the analysis.

## Office Data

The data gathered in the field as described previously were transcribed in the office onto code sheets (Fig. 7). In addition to the highway number and beginning milepost number reading in Cols. 2 and 3 of the code sheet, an identifying code was used in Col. 1 to identify the city, county, and population group of the city.

Col. 4 shows the length of each section in $\frac{1}{100}$ mile, and Col. 5 shows the average traffic volume in hundreds of vehicles per day. Cols. 6 through 9 code the frequency of the respective roadway elements per mile of section. These values were obtained by multiplying the reciprocal of the length of the section by the frequency of these elements as indicated on the field sheet. For example, if a section was $\frac{1}{10}$ mile long and

| City Code County-City Population | Highway No. | Beg. M.P. | Length .01's mi. | ADT | Comm. Units/mi. | Cdws/mi. | Resid. Units/mi. | Rdws/mi. | Urb. Code | Cult. Code | Inter./mi. | Signals per mi. | Channels per mi. | Speed | Pavement | Shldr. | Lane No. | Mdn. Width | Mdn. Code | Dark Code | Ef. Lane | Non-inter. accidents per m.v.m. | Inter. accidents per m.v.m. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) | (18) | (19) | (20) | (21) | (22) | (23) | (24) |
| 09011 | 015 | 09227 | 012 | 016 | 067 | 100 | 017 | 008 | 1 | 0 | 008 | 000 | 000 | 25 | 44 | 05 | 2 | 00 | 0 | 0 | 19 | 00000 | 00000 |
| | 015 | | | | | | | | | | | | | | | | | | | | | | |
| 09011 | 015 | 09239 | 009 | 018 | 033 | 044 | 078 | 011 | 1 | 2 | 022 | 000 | 000 | 25 | 44 | 03 | 2 | 00 | 0 | 0 | 17 | 00850 | 00850 |
| 09011 | 015 | 09248 | 018 | 020 | 094 | 039 | 017 | 011 | 1 | 2 | 017 | 000 | 000 | 25 | 49 | 00 | 2 | 00 | 0 | 0 | 16 | 00000 | 00382 |
| 09011 | 015 | 09266 | 007 | 019 | 043 | 057 | 014 | 014 | 1 | 0 | 014 | 000 | 000 | 25 | 48 | 06 | 2 | 00 | 0 | 0 | 22 | 00000 | 00000 |
| 09011 | 015 | 09273 | 019 | 018 | 016 | 026 | 005 | 005 | 1 | 0 | 021 | 000 | 000 | 25 | 23 | 06 | 2 | 00 | 0 | 0 | 10 | 00000 | 00000 |

Figure 7. Urban roadway elements study by Oregon State Highway Department.

had 3 commercial driveways, the commercial driveways per mile would be 30. Col. 10 was used to indicate whether a section was within or without the corporate limits of a city by coding zero for suburban and one for corporate sections.

The culture classification of each section was coded in Col. 11 with 0, 1, and 2 as the code for business, residential, and mixed, respectively. Cols. 12 through 14 were used for recording intersectional and traffic signal data. For these items the frequency per mile was coded. Cols. 15 through 19 were coded direct from the field sheets. Col. 20 was used to indicate whether a median was mountable or unmountable with a code of zero or one, respectively. The type of parking for each section was indicated in Col. 21 by using a code of zero for parallel, one for angle, and two for no parking; and three for no parking on one side and parallel on the other, and four for angle parking and parallel parking combined.

Col. 22 indicated to the nearest foot the effective lane width. This value was obtained by taking the total pavement width less the distance necessary for the type of parking which was permitted, divided by the number of lanes. Eight ft was allowed for parallel parking and 18 ft for angle parking on each side of the street. Thus, for a roadway 60 ft from curb to curb which allowed angle parking on both sides, the effective lane width would be 60 ft minus 36 ft divided by 2 lanes, for an effective lane width of 12 ft. If a section had a shoulder width of more than 6 ft, it was assumed that parking would be on the shoulder and no reduction was made in the pavement width.

The accident data recorded in Cols. 23 and 24 were obtained from office records. The frequency of accidents on each section was converted into accident rates and appears in terms of accidents per million vehicle miles. Accident rates were entered separately for intersectional and non-intersectional accident rates.

# *Appendix B*

## IBM PROCEDURE

The data on the completed code sheets were punched onto IBM cards. The code sheets were retained as duplicate records, but no further direct work involved them. The first step in the IBM procedure was the computation of the total accident rate, that is, the sum of the intersectional and non-intersectional accident rates. The IBM calculating punch type 602-A was used in the summation, and in this way the total accident rates were punched on the card from which the intersectional and non-intersectional rates were read. In the next step of the IBM computations, the sums of squares and the sums of the cross products among all the factors were developed. The 602-A punched these sums in summary cards following the deck of data cards. This same deck of data cards was then processed from the IBM accounting machine which printed the totals of each factor. In these two operations, all the data necessary in the computation of correlation coefficients were made available (assuming the sample size was known). In actual practice these operations were preceded by a stratification on the basis of desired grouping by means of the IBM sorter.

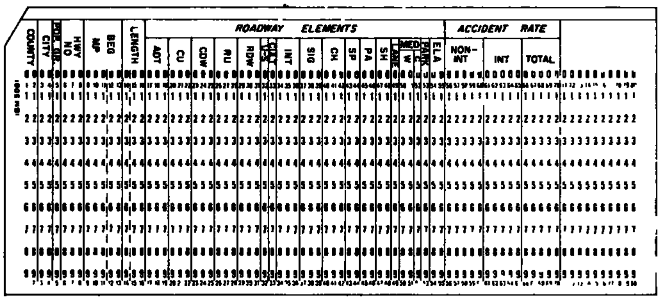

Figure 8. IBM card layout—roadway elements study.

A sample IBM card appears in Figure 8. A detailed description of the information appearing there is as follows: county, city, population codes (Cols. 1 through 5), highway number (Cols. 6 to 8), beginning M. P. (Cols. 9 through 13), length of section in hundredths of a mile (Cols. 14 through 16), ADT (Cols. 17 through 19), commercial units per mile (Cols. 20 to 22), commercial driveways per mile (Cols. 23 through 25), residential units per mile (Cols. 26 through 28), residential driveways per mile (Cols. 29 through 31), urban code (Col. 32), culture code (Col. 33), intersections per mile (Cols. 34 through 36), signals per mile (Cols. 37 through 39), channels per mile (Cols. 40 to 42), speed limit (Cols. 43, 44), pavement width (Cols. 45 through 46), shoulder width (Cols. 47 through 48), number of lanes (Col. 49), median width (Col. 50, 51), median code (Col. 52), parking code (Col. 53), effective lane (Cols. 54 and 55), nonintersectional accidents per million vehicle miles (Cols. 56 through 60), intersectional accidents per million vehicle miles (Cols. 61 through 65), and total accidents per million vehicle miles (Cols. 66 through 70). As mentioned before, the data in Cols. 1 through 65 were key punched onto the card, whereas the data in Cols. 66 through 70 were calculated using the 602-A and punched onto the same card.

## *Appendix C*

### MULTIPLE CORRELATION TECHNIQUE

The analytic procedures employed in this study were attempts to evaluate the individual contributions of various roadway factors and ultimately the joint effects of the several roadway elements taken together upon the accident experience. The multiple correlation technique is ideally suited to this end since it is designed to provide an estimate of the over-all relationship between several factors and a given factor. In this

TABLE 7

ILLUSTRATION OF MULTIPLE CORRELATION TECHNIQUE

Part 1 Intercorrelations, means, and standard deviations of the data of the multiple correlation illustrations.

Two-Lane Urban, 10,000 and over ADT

| | Intercorrelations (r) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $X_3$ (CU) | $X_4$ (CDW) | $X_5$ (INT) | $X_6$ (SIG) | $X_7$ (SP) | $X_1$ (A) | $M_x$ Mean | $\sigma_x$ Standard Deviation |
| $X_2$ (ADT) | 0 1794 | 0 0748 | 0.1795 | 0 1470 | -0.1502 | 0.4190 | 119.231 | 16 439 |
| $X_3$ (CU) | - | 0.5751 | 0 6251 | 0.6259 | -0.4283 | 0 6684 | 53.615 | 49.516 |
| $X_4$ (CDW) | - | - | 0 4314 | 0.3279 | -0.5343 | 0.4386 | 31 538 | 18.731 |
| $X_5$ (INT) | - | - | - | 0 3861 | -0.4102 | 0.5327 | 15.577 | 6 968 |
| $X_6$ (SIG) | - | - | - | - | -0 3391 | 0.8485 | 2.462 | 3 003 |
| $X_7$ (SP) | - | - | - | - | - | -0.4363 | 31 538 | 7.308 |
| $X_1$ (A) | - | - | - | - | - | - | 19.055 | 17.571 |

TABLE 8

ILLUSTRATION OF MULTIPLE CORRELATION BY THE DOOLITTLE METHOD
Two-Lane Urban and Suburban, ADT 10,000 and over
Part 2

| Column Number | | 2 | 3 | 4 | 5 | 6 | 7 | 1 | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | | ADT | CU | CDW | INT | SIG | SP | A | Check Sum |
| Row | Instructions | | | | | | | | |
| A | $r_2K$ | 1.0000 | 0.1794 | 0.0748 | 0.1795 | 0.4170 | -0.1502 | 0.4190 | 2.1195 |
| B | $A \div (-A_2)$ | -1.0000 | -0.1794 | -0.0748 | -0.1795 | -0.4170 | 0.1502 | -0.4190 | -2.1195 |
| C | $r_3K$ | (0.1794) | 1.0000 | 0.5751 | 0.6251 | 0.6259 | -0.4283 | 0.6684 | 3.2456 |
| D | $A \times B_3$ | (-0.1794) | -0.0332 | -0.0134 | -0.0322 | -0.0748 | 0.0269 | -0.0752 | -0.3802 |
| E | $C + D$ | | 0.9678 | 0.5617 | 0.5929 | 0.5511 | -0.4014 | 0.5932 | 2.8654 |
| F | $E \div (-E_3)$ | | -1.0000 | -0.5804 | -0.6126 | -0.5694 | 0.4148 | -0.6129 | -2.9607 |
| G | $r_4K$ | (0.0748) | (0.5751) | 1.0000 | 0.4314 | 0.3279 | -0.5343 | 0.4386 | 2.3155 |
| H | $A \times B_4$ | (-0.0748) | (-0.0134) | -0.0056 | -0.0134 | -0.0312 | 0.0112 | -0.0313 | -0.1585 |
| I | $E \times FA$ | | (-0.5617) | -0.3260 | -0.3441 | -0.3199 | 0.2330 | -0.3443 | -1.6631 |
| J | $G + H + I$ | | | 0.6684 | 0.0739 | -0.0232 | -0.2901 | 0.0630 | 0.4919 |
| K | $J \div (-J_4)$ | | | -1.0000 | -0 1106 | 0.0347 | 0.4340 | -0.0943 | -0.7359 |
| L | $r_5K$ | (0.1795) | (0.6251) | (0.4314) | 1 0000 | 0.3861 | -0.4102 | 0.5327 | 2.7446 |
| M | $A + B_5$ | (-0.1795) | (-0.0332) | (-0.0134) | -0.0322 | -0.0749 | 0.0270 | -0.0752 | -0.3804 |
| N | $E \times F_5$ | | (-0.5929) | (-0.3441) | -0.3632 | -0.3376 | 0.2459 | -0.3634 | -1.7553 |
| O | $J \times K_5$ | | | (-0.0739) | -0.0082 | 0.0026 | 0.0321 | -0.0070 | -0.0544 |
| P | $L + M + N + O$ | | | | 0.5964 | -0.0238 | -0.1052 | 0.0871 | 0.5545 |
| Q | $P \div (-P_5)$ | | | | -1.0000 | 0.0399 | 0.1764 | -0.1460 | -0.9297 |
| R | $r_6K$ | (0.4170) | (0.6259) | (0.3279) | 0.3861 | 1.0000 | -0.3391 | 0.8485 | 3.2663 |
| S | $A \times B_6$ | (-0.4170) | (-0.0748) | (-0.0312) | (-0.0749) | -0.1739 | 0.0626 | -0.1747 | -0.8838 |
| T | $E \times F_6$ | | (-0.5511) | (-0.3198) | (-0.3376) | -0.3138 | 0.2286 | -0.3378 | -1.6316 |
| U | $J \times K_6$ | | | (0.0232) | (0.0026) | -0.0008 | -0.0101 | 0.0022 | 0.0171 |
| V | $P \times Q_6$ | | | | 0.0238 | -0.0009 | -0.0042 | -0.0035 | -0.0221 |
| W | $R + S + T + U + V$ | | | | | 0.5106 | -0.0622 | 0.3417 | 0.7901 |
| X | $W \div (-W_6)$ | | | | | -1.0000 | 0.1218 | -0.6692 | -1.5474 |
| A' | $r_7K$ | (-0.1502) | (-0.4283) | (-0.5343) | (-0.4102) | (-0.3391) | 1.0000 | -0.4363 | -1.2984 |
| B' | $A \times B_7$ | (0.1502) | (0.0269) | (0.0112) | (0.0270) | (0.0626) | -0.0226 | 0.0629 | 0 3183 |
| C' | $E \times F_7$ | | (0.4014) | (0.2330) | (0.2459) | (0.2286) | -0.1665 | 0.2461 | 1.1886 |
| D' | $J \times K_7$ | | | (0.2901) | (0.0321) | (-0.0101) | -0.1259 | 0.0273 | 0.2135 |
| E' | $P \times Q_7$ | | | | (0.1052) | (-0.0042) | -0.0186 | 0.0154 | 0.0978 |
| F' | $W \times X_7$ | | | | | (0.0622) | -0.0076 | 0.0416 | 0.0962 |
| G' | $A' + B' + C' + D' + E' + F'$ | | | | | | 0.6588 | -0.0430 | 0.6160 |
| H' | $G \div (-G_7)$ | | | | | | -1.0000 | 0.0653 | -0.9350 |

study the given factor was always the accident rate whether this be for non-intersectional, intersectional, or total accidents. The multiple correlation procedure provides two valuable forms of information. First, it provides a coefficient of multiple correlation (R) which expresses quantitatively the extent of association between the several factors and the accident rates. This multiple correlation coefficient varies from 0 to 1. The stronger the relationship between these various roadway factors and accident rates, the larger R becomes. If there is no relationship, R equals 0; if there is perfect relationship, R equals 1. The second important result of the multiple correlation technique is the development of a multiple regression equation. The multiple regression equation is a statement of the theoretical contribution of the various roadway elements to the accident rate. The effectiveness of the multiple regression coefficient and equation depends on the predictive factors selected for study.

In other words, if there are 20 factors, the regression equation's usefulness will depend upon the particular variables chosen for analysis. Thus, it would be impractical to evaluate the separate contributions of all the factors when it can be assumed that many of the 20 variables will be of little or no appreciable value. The decision as to which variables to include is made on the basis of the variable's relationship to the accidents recorded. A quantitative measure of these relationships is given by the Pearsonian correlation coefficient:

$$r = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{N\Sigma X^2 - (\Sigma X)^2}\sqrt{N\Sigma Y^2 - (\Sigma Y)^2}} \quad (1)$$

TABLE 9

ILLUSTRATION OF MULTIPLE CORRELATION TECHNIQUE
Two-Lane Urban and Suburban, ADT 10,000 and Over

A Check of the Back Solution of the Normal Equation

The Back Solution

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $\beta_{17.23456}$ | | | | | | -0.0653 = | -0.0653 | (-HI) |
| $\beta_{16.23456}$ | | | | | 0 6612 = | -0.0080 | +0.6692 | (-XI) |
| $\beta_{15.23456}$ | | | | 0 1609 = | +0 0264 | -0.0115 | +0 1460 | (-QI) |
| $\beta_{14.23456}$ | | | 0 0711 = | -0.0178 | +0 0229 | -0.0283 | +0.0943 | (-KI) |
| $\beta_{13\ 23456}$ | | 0 0694 = | -0.0413 | -0.0986 | -0.3765 | -0 0271 | +0 6129 | (-FI) |
| $\beta_{12\ 23456}$ | 0.0868 = | -0 0125 | -0 0053 | -0.0289 | -0.2757 | -0.0098 | +0 4190 | (-BI) |

Note: The Beta Coefficients found at the left of each row are the algebraic sums of the values to the right of the equal sign: i e $\beta_{15\ 23467}$ = 0.0264 - 0.0115 + 0 1460

A Check of the Back Solution

| $X_K$ | | $\beta_{1K}$ | $rK_7$ | $\beta_{1KrK_7}$ |
|---|---|---|---|---|
| X | ADT | 0.0868 | -0.1502 | -0 0130 |
| X | CU | 0 0694 | -0 4283 | -0.0297 |
| X | CDW | 0 0711 | -0.5343 | -0 0380 |
| X | INT | 0.1609 | -0.4102 | -0.0660 |
| X | SIG | 0 6612 | -0.3391 | -0 2242 |
| X | SP | -0 0653 | 1.0000 | -0 0653 |
| X | A | | $r_{17}$ = -0.4363 $\Sigma\beta_{1KrK_7}$ | -0.4362 |

in which:

N = Number of sections;
$\Sigma X$ = Sum of the X-factor values (e.g., sum of CDW);
$\Sigma Y$ = Sum of the Y-factor values (e.g., sum of accident rates);
$\Sigma Y^2$ = Sum of the squared Y-factors;
$\Sigma X^2$ = Sum of the squared X-factors; and
$\Sigma XY$ = Sum of the X and Y crossproducts.

As shown in Eq. 1, the two sums of squares, the sum of the crossproducts, the two individual sums, and the sample size, are the only data required for the calculation. The results of the IBM computations described in Appendix B provided this information. Insertion in Eq. 1 and the subsequent calculation was accomplished by a desk calculator. After a large portion of the analysis had been completed, an IBM 650 became available and a program was obtained which computed all the zero order correlations and the final regression equations. This reduced tremendously the amount of desk calculator work required in making the computations.

In a general way, the factors which will have the most value in a multiple regression technique or multiple regression equation, are those which are most highly correlated with the factor that is to be predicted, and at the same time related to the slightest extent to the other predicting factors. In the example that will be illustrated shortly these most valuable factors are: average daily traffic, commercial units, commercial driveways, intersections, signals, and speed. This example shows the development of the equations for prediction of accident rates on 2-lane urban roadways with an ADT of 10,000 and over. The zero order correlations between the various factors and the accident rates are shown in Table 7, along with the means and the standard deviations of each of the factors concerned (the mean is the same as the arithmetic average, and the standard deviation is the standard way of presenting the amount of variability within the group). All the data are available which are necessary to proceed with the development of the multiple correlation coefficient and the multiple regression equation.

Eq. 2 is used to develop the coefficient of multiple correlation.

$$R_{1.234567} = \sqrt{\beta_{12}r_{12} + \beta_{13}r_{13} + \beta_{14}r_{14} + \beta_{15}r_{15} + \beta_{16}r_{16} + \beta_{17}r_{17}} \quad (2)$$

All the information necessary to solve this equation is contained in Tables 7, 8, and 9. This illustrates the method of multiple correlation developed by Doolittle.[4] Substituting the appropriate values, the multiple correlation coefficient becomes 0.888.

Table 9 provides the check of the Back Solution of the Beta coefficients shown in the table. The next step in the multiple correlation technique is the development of a multiple regression equation. This is shown in Eq. 3.

$$Y = a + b_{12}M_2 + b_{13}M_3 + b_{14}M_4 + b_{15}M_5 + b_{16}M_6 + b_{17}M_7 \quad (3)$$

The coefficients shown in Eq. 3 are developed as shown in Eqs. 4, 5, 6, 7, 8, and 9:

$$b_{12} = (\sigma_1/\sigma_2)\,\beta_{12} \quad (4)$$

$$b_{13} = (\sigma_1/\sigma_3)\,\beta_{13} \quad (5)$$

$$b_{14} = (\sigma_1/\sigma_4)\,\beta_{14} \quad (6)$$

$$b_{15} = (\sigma_1/\sigma_5)\,\beta_{15} \quad (7)$$

$$b_{16} = (\sigma_1/\sigma_6)\,\beta_{16} \quad (8)$$

$$b_{17} = (\sigma_1/\sigma_7)\,\beta_{17} \quad (9)$$

where $\sigma_1$, $\sigma_2$, $\sigma_3$, $\sigma_4$, $\sigma_5$, $\sigma_6$, $\sigma_7$, are the standard deviations of accident rates, average daily traffic, commercial units, commercial driveways, intersections, signals, and speed, respectively. The Beta Coefficients are those shown in Table 9.

The a coefficient of Eq. 10 is developed by subtracting the products of the various b coefficients, times their means (M) from the mean of the predicted value, in this case the mean of the accidents.

$$a = M_1 - b_{12}M_2 - b_{13}M_3 - b_{14}M_4 - b_{15}M_5 - b_{16}M_6 - b_{17}M_7 \quad (10)$$

Substituting the appropriate values, the multiple regression equation becomes that shown in Table 5. The equation is repeated in Eq. 11.

$$A = -18.21 + 0.09\ ADT + 0.25\ CU + 0.07\ CDW + 0.41\ INT + 3.87\ SIG - 0.16\ SP \quad (11)$$

For example, if a particular 1-mile section in this volume range had a 35-mile indicated speed, 14 intersections, 59 commercial units, 49 commercial driveways, 2 signals, and an average daily traffic of 10,800, the predicted number of accidents would be derived as follows:

$$A = -18.21 + 0.09(108) + 0.25(59) + 0.07(49) + 0.41(14) + 3.87(2) - 0.16(35)$$

$$A = -18.21 + 9.72 + 14.75 + 3.43 + 5.74 + 7.74 - 5.60 = 17.57 \text{ Accidents/mvm}$$

[4] Guilford, J. P., "Psychometric Methods." McGraw-Hill Book Company, p. 393-399, (1936).