Predicting Traffic Accidents from Roadway Elements of Rural Two-Lane Highways With Gravel Shoulders

DAVID W. SCHOPPERT, Engineer Economist
Oregon State Highway Department

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 rural 2-lane highways from roadway elements such as ADT, lane width, shoulder width, sight distance restrictions, commercial and residential driveways, and intersections.

A sample of nearly 1,400 miles of 2-lane highways was utilized. The data were analyzed through the use of multiple correlation techniques. The result of the analysis is a series of equations which can be used to predict total accidents on rural 2-lane highways in Oregon.

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

1. Motor vehicle accidents are directly related to vehicle volumes and certain physical features of the highway. This relationship is strong enough in the higher ADT ranges to make possible reasonably accurate predictions of total accidents on the basis of known physical features.

2. Access to the highway through driveways or intersections is directly related to accidents at all ADT levels. The number of access points is a reasonably good predictive index of the number of potential accidents within an ADT group.

3. Although the highway design elements such as lane width, shoulder width, and sight distance restriction are related to accidents, they do not ordinarily serve as good predictors of the number of accidents. Generally speaking, wider lanes, wider shoulders, and unimpaired sight distance result in a safer highway.

4. An analysis of the data presented in this report confirms the theory that accidents are essentially chance occurrences resulting from errors in judgment. The number of accidents increases with the number of situations presenting a change in conditions, and therefore requiring a decision on the part of the motor vehicle operator. These data confirm this theory in the following ways:

(a). Accidents on low volume roads do not appear to be related to any roadway feature.

(b). Accidents increase when: (1) vehicle volumes increase, (2) access points increase, (3) sight distance is impaired, (4) the cross-section is reduced.

● MODERN HIGHWAYS return to the road user certain monetary benefits from savings in time, travel distance, and operating costs. Many of these individual benefits can be measured or estimated before completion of a given project, and the total benefits derived. This is a common practice for major improvements, and the ratio of benefits to costs serves as a valuable tool for selecting one of two or more alternate routes between common termini.

An important benefit which cannot presently be measured is that which the road user realizes from a safer highway. It is recognized that a wide cross-section, good alignment, control of access to abutting lands, and elimination of intersections at grade result in a safer highway. However, no quantitative analysis has been made which will permit an estimate of the relative benefits accruing to the road user through a reduction in accidents, when an obsolete or congested facility is replaced with one of modern design. To arrive at an estimate of these benefits, it would be necessary to have at hand certain techniques which would permit a prediction of the number of accidents likely to occur both on the new and the old facility. This study was undertaken with the hope that such techniques could be developed.

It was recognized from the outset that the measurable elements such as the design features, ADT, points of access, and usage of abutting lands might not figure heavily enough in accident causation to permit accurate predictions unless other less tangible factors were known. Although accurate predicting equations might not result, it was felt that the study would provide a better understanding of the relationship between accidents and roadway design and usage.

This study is only a portion of the over-all effort. In this portion, the relationship between traffic accidents and roadway elements for rural 2-lane highways with gravel shoulders was investigated. Another study which will investigate the same relationships for urban and suburban highways is currently underway. Presuming that accidents can be predicted with reasonable accuracy for all of the various highway types, a separate study of accident costs will have to be conducted either independently or in cooperation with other agencies.

It was also recognized that the method must be kept simple to permit maximum usage. Throughout the study, a balance between reasonable accuracy and ease of operation was sought. It is entirely possible that more accuracy could be obtained by gathering data on the entering volumes at driveways and intersections, but it is doubtful if the additional time and effort would compensate for the gain in accuracy in the light of the uses to which the results will be put.

The study is based on a sample of 1,374 miles of 2-lane rural highway with gravel shoulders. The accident histories of these sections during the 3-year period from January 1, 1952 to December 31, 1954 were used together with ADT for the year 1953. The lane width, shoulder width, number of commercial driveways, number of residential driveways, number of intersections, and percent of the highway with less than 1,500-ft sight distance were recorded in the field.

These data were analyzed by statistical techniques to determine the relationship between accidents and the various roadway elements. Regression equations were developed and nomographs were drawn to facilitate solution of the individual equations.

Although the predictions obtained from the equations are not precisely accurate, they represent the best information available at this time. It is possible that the accuracy can be improved by further study of various elements, one of which is intersectional accidents. For this reason, predicting equations were developed for non-intersectional accidents, and the analysis of non-intersectional accidents is included in this report is some detail. If and when intersectional accidents can be predicted separately, the non-intersectional accidents can be predicted from the equations (Appendix B) and the two added together for total accidents. Until such time, the equations for total accidents are recommended for use. Their accuracy is such that predictions should only be attempted for periods of three or more years and sections four or more miles in length.

DATA SOURCES

Field Data

The field data were obtained on state primary highway routes chosen to include only rural 2-lane roadways with gravel shoulders. Any sections which had new construction beginning in 1952 or later were eliminated. Field observers recorded measurements of the following elements: (1) lane width (LA); (2) shoulder width (SH); and (3) sight distance restriction (SDR). The abbreviations shown were used to describe these elements in all tables and equations. The following is a list of abbreviations used for the other roadway elements.

(a) A - motor vehicle accidents
(b) ADT - average daily traffic
(c) CAP - capacity
(d) CDW - commercial driveways
(e) CONG - congestion
(f) INT - intersections
(g) RDW - residential driveways

TABLE 1

DISTRIBUTION OF 1-MILE SECTIONS BY ADT RANGES

ADT Range	Section of Oregon	Number of 1-Mile Sections
0 - 999	All	404
1,000 - 1,999	All	343
2,000 - 2,999	Western	190
3,000 - 3,999	Western	73
4,000 - 4,999	Western	57
5,000 - 5,999	Western	41
6,000 - 7,999	Western	42
2,000 - 2,999	Eastern	173
3,000 and over	Eastern	51
		1,374

A detailed description of the field pro cedure, along with a sample field sheet appears in Appendix A. No field data were recorded for those sections which were speed zoned or which were obviously non-rural in nature, as in the case where high congestion and an excessive number of commercial driveways existed. With the exception of these sections, the observers recorded the required field data for each consecutive 1-mile section. In this way, over 1,400 miles of highway were surveyed and constitute the broadest possible sample.

Traffic Data

In the analysis described in the text, the roadway elements and accident relationships were considered within traffic volume groups, thus, the 1,374 usable 1-mile sections of highway were grouped in terms of ADT. The average daily traffic, ranging from 100 to 8,000 was taken from Traffic Volume Tables for 1953 published by the Oregon State Highway Department. The 1953 data corresponded to the mid-year of the 3-year accident data employed, and ADT was assigned to each 1-mile section. If more than 10 percent traffic volume change occurred within a given 1-mile section, the section was excluded from further consideration. The result of this procedure was a breakdown of the 1,374 1-mile sections into convenient ADT ranges. This breakdown of the total sample into ADT ranges is shown in Table 1.

Traffic data were considered especially important for two reasons: (1) the rather obvious direct relationship between accident occurrence and traffic volumes made it probable that this factor would be one of the most important characteristics in terms of accident prediction; and (2) it was necessary to control, or at least to take into account, the joint effects of ADT with other roadway features such as lane width and shoulder width which were evaluated in terms of their separate contributions to accident frequency. Without such controls, it would be virtually impossible to isolate the effects of these roadway features on accident data. For example, if it were found that accident frequency increases with lane width, this might be, at least partially, because lane width is one roadway element that is frequently altered to accommodate the de-

TABLE 2

THE RANGES AND MEANS OF THE ROADWAY FACTORS WITHIN AVERAGE DAILY TRAFFIC GROUPS[a]

ADT Range	Section of Oregon	Shoulder Width (SH) ft	Lane Width (LA) ft	Sight Restriction (SDR) %	Commercial Driveways (CDW)	Residential Driveways (RDW)	Intersections (INT)
0 - 999 (500)	All	1 to 7 (2.84)	8 to 11 (9.39)	0 to 100 (58.17)	0 to 7 (0.49)	0 to 11 (0.86)	0 to 4 (0 45)
1,000 - 1,999 (1,450)	All	1 to 10 (4.14)	8 to 12 (10.15)	0 to 100 (71.97)	0 to 11 (0.94)	0 to 32 (2 00)	0 to 6 (1.13)
2,000 - 2,999 (2,360)	Western	1 to 11 (5.42)	9 to 12 (10.77)	0 to 100 (71.63)	0 to 14 (1.69)	0 to 18 (0 95)	0 to 5 (1 00)
3,000 -3,999 (3,340)	Western	2 to 13 (6.84)	9 to 13 (10.88)	0 to 100 (59.45)	0 to 13 (2.08)	0 to 21 (3.93)	0 to 7 (1 64)
4,000 - 4,999 (4,370)	Western	3 to 14 (8 04)	9 to 13 (11.18)	0 to 100 (49 47)	0 to 41 (4 14)	0 to 22 (4.58)	0 to 7 (1 75)
5,000 - 5,999 (5,340)	Western	3 to 12 (7 49)	10 to 14 (11 05)	0 to 100 (57 44)	0 to 16 (4.68)	0 to 37 (3 54)	0 to 7 (2 07)
6,000 - 7,999 (6,840)	Western	3 to 14 (9.17)	10 to 13 (11 17)	0 to 100 (40.83)	0 to 14 (3.17)	0 to 28 (2 76)	0 to 6 (2.02)
2,000 - 2,999 (2,350)	Eastern	1 to 10 (4.98)	9 to 13 (10.70)	0 to 100 (29 83)	0 to 7 (0.50)	0 to 22 (1 52)	0 to 5 (0.90)
3,000 and above (3,400)	Eastern	1 to 7 (4 49)	10 to 12 (10.88)	0 to 100 (28 24)	0 to 13 (2 25)	0 to 22 (4.59)	0 to 4 (1.29)

[a] The mean values for each roadway element appear in parenthesis immediately below the range of values for that particular element.

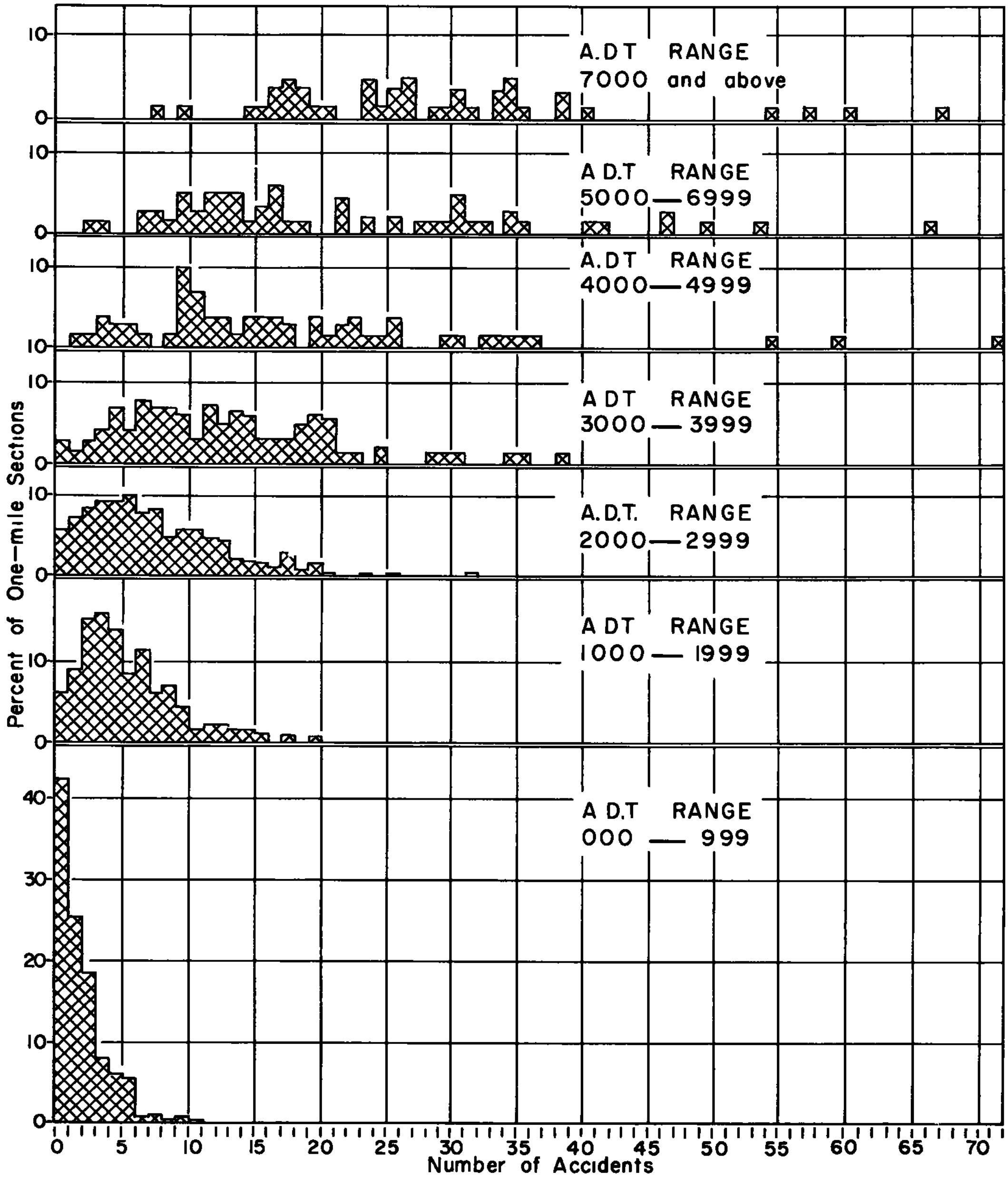


Figure 1. The percentage distribution of 1-mile sections by number of total accidents for various ADT ranges.

mands of traffic volumes; thus, a strong relationship between accident frequency and lane width might actually reflect the influence of the higher volumes which are generally encountered on highways with wide lanes. A rough picture of the various factors in each ADT range is given in Table 2.

In this table, the ranges and means of the roadway factors within each ADT group are presented. Examination reveals that both shoulder width and lane width tend to increase from the lower ADT ranges to the higher ones. No very obvious trend for the various ADT ranges occurs for sight restrictions. Commercial driveways, on the other hand, appear to increase directly with the ADT range involved. No such systematic trend appears for residential driveways. Intersections, like commercial driveways, however, tend to increase in the higher ADT groups. The tendencies of shoulder width, lane width, commercial driveways and intersections to increase with ADT points to the necessity for analyzing the data within the different ADT ranges.

Accident Data

The accident data used in this study were available from office records. Total accidents for the years 1952, 1953, and 1954 were used because of the variation in the number of accidents from year to year for a given section of highway. The 3-year total tends to give less variation in the data.

The accidents were tabulated by location, either intersectional or non-intersectional, and by severity; that is, property damage, personal injury, and fatal accidents. For the major share of the analysis, all types and locations were added together and referred to as total accidents. At all times the number of accidents quoted here are in terms of 3-year totals for a 1-mile section of highway, except when treating with accident prediction equations.

The distribution of total accidents within each ADT range is shown in Figure 1. Examination of this figure reveals that on low volume roads (that is, 0-999 ADT) the bulk of the sections had 5 or less accidents. In marked contrast, the majority of the sections in the ADT range above 5,000 had 10 or more accidents per section. Not only the typical number of accidents, but also the variability of the accident data increased as the ADT increased. The lowest volume group had a range of 0 to 10 accidents. By contrast, the range was from 7 to 67 accidents in the highest ADT group. This represents an increased range of accidents of approximately 6 to 1 as volumes increased from the lowest to the highest ADT groups.

ANALYSIS

Several methods of analysis were attempted during the study. The one to be described below gave the most usable results. No attempt will be made at this point to describe the detailed techniques used in the various analyses. The procedures described therein were common to all of the analyses. Appendix B contains a complete description of the various attempts to analyze the data which did not yield usable results or which did not yield results as satisfactory as those described below.

The first step in the analysis was to group the data by ADT and subdivide the various highway sections according to their location. Thus, seven ADT groups were obtained for sections in western Oregon and two were obtained for sections in eastern Oregon. The analysis of the data for sections with less than 2,000 ADT followed the same procedures described below, but did not yield usable results. Further efforts to obtain usable results are described later.

The zero order correlation coefficients between the various roadway elements and accidents were calculated (Table 3). ADT has a positive correlation with accidents in all ADT ranges, although the relationship varies in strength.

Sight distance restriction is generally positively correlated with accidents, indicating that more accidents can be expected on sections of highway with a high percentage of sight restriction. However, when sight distance restriction was included in the re-

TABLE 3

ZERO ORDER CORRELATIONS BETWEEN ROADWAY ELEMENTS AND TOTAL ACCIDENT OCCURRENCES IN ADT GROUPS

Group Identification			Accident-Roadway Elements Correlations						
Part of Oregon	ADT Range	Number of 1-Mile Sections	ADT	SDR	LA	SH	CDW	RDW	INT
Western	2,000 - 2,999	190	0.186[a]	0.130	-0.053	-0.167[a]	0.231[a]	0.084	0.191[a]
Western	3,000 - 3,999	73	0.028[a]	0.484	-0.254[a]	-0.571[a]	0.488[a]	0.027	0.160[a]
Western	4,000 - 4,999	57	0.206	0.430	-0.161	-0.549[a]	0.530[a]	0.428[a]	0.589[a]
Western	5,000 - 5,999	41	0.089	0.025	0.058	-0.103	0.275[a]	0.514[a]	0.583[a]
Western	6,000 - 7,999	42	0.329[a]	0.107	0.022	-0.170	0.451[a]	0.536[a]	0.354[a]
Eastern	2,000 - 2,999	173	0.096	-0.088	0.030	-0.063	0.400[a]	0.316[a]	0.350[a]
Eastern	3,000 and over	51	0.568[a]	0.266	-0.126	0.142	0.781[a]	0.573[a]	0.616[a]

[a] Factors employed in the regression equations described in the text.

TABLE 4

MULTIPLE CORRELATIONS BETWEEN ROADWAY ELEMENTS AND TOTAL ACCIDENTS

Part of Oregon	ADT Range	Best Predictors[a]	Coefficient of Multiple Correlation	Standard Error of Estimate	Ratio of the Standard Error of Estimate to the Mean
Western	2,000 - 2,999	ADT-SH-CDW-INT	0. 362	4. 57	0 49
Western	3,000 - 3,999	SDR-LA-SH-CDW-INT-ADT	0 684	5 82	0. 44
Western	4,000 - 4,999	SDR-SH-CDW-RDW-INT	0. 813	8 07	0 45
Western	5,000 - 5,999	CDW-RDW-INT	0. 713	9 00	0 42
Western	6,000 - 7,999	ADT-CDW-RDW-INT	0 663	10 85	0 46
Eastern	2,000 - 2,999	CDW-RDW-INT	0 476	3. 05	0. 75
Eastern	3,000 and over	ADT-SDR-CDW-RDW-INT	0 852	3 44	0. 35

[a] These elements were used in the regression equations described in the text.

gression, the effect was so small that it is not included in the equations.

Lane width shows important relationships in some, but not all, ADT ranges. The higher correlations are negative, indicating that less accidents can be expected on roadways with wide lanes, but this relationship is not consistent in all ADT ranges. It will be recalled that lane width increased with increasing ADT's (Table 2), and also that the range in lane width is usually not more than 4 ft.

Shoulder width shows strong relationships in some ranges, and is negative in all but one. It too, was strongly related to ADT and pavement width. Commercial driveways show a strong positive relationship to accidents in all ADT ranges. The number of commercial driveways is also related to ADT (Table 2).

Residential driveways showed a positive relationship to accidents in all ADT ranges, but the strength of this relationship varies from one range to another. The number of residential driveways was not so closely related to ADT as was the number of commercial driveways.

Intersections showed a positive relationship to accidents in all ADT ranges. This relationship was not particularly strong in the low ADT ranges for western Oregon.

On the basis of the zero order correlations (Table 3) and on the basis of the intercorrelations between the various roadway elements, the coefficients of multiple correlation were calculated for the relationship between certain combinations of roadway elements and accidents. These multiple correlations, together with the standard errors of estimate and the ratios of the standard error of estimate to the mean number of accidents, are shown in Table 4. Also shown in this table are the roadway elements which were combined in the regression equations.

The regression equations developed from this analysis are as follows:

For highways in western Oregon:

1W when the ADT is between 2,000 and 2,999

$$A = 1.07 + 0.10\ ADT - 0.16\ SH + 0.11\ CDW + 0.24\ INT$$

2W when the ADT is between 3,000 and 3,999

$$A = -2.12 + 0.50\ LA - 0.58\ SH + 0.35\ CDW + 0.21\ INT + 0.12\ ADT$$

3W when the ADT is between 4,000 and 4,999

$$A = 7.32 + 0.01\ SDR - 0.61\ SH + 0.07\ CDW + 0.06\ RDW + 1.37\ INT$$

4W when the ADT is between 5,000 and 5,999

$$A = 3.67 + 0.01\ CDW + 0.28\ RDW + 1.17\ INT$$

5W when the ADT is between 6,000 and 7,999

$$A = -10.66 + 0.23\ ADT + 0.17\ CDW + 0.45\ RDW + 0.49\ INT$$

For highways in eastern Oregon:

1E when the ADT is between 2,000 and 2,999

$$A = 0.95 + 0.28\ CDW + 0.24\ INT + 0.04\ RDW$$

2E when the ADT is 3,000 or over

$$A = -0.26 + 0.34\ CDW + 0.33\ INT + 0.08\ RDW + 0.05\ ADT + 0.01\ SDR$$

in which

A = total accident experience for a 1-mile section in a 1-year period;
ADT = average daily traffic divided by 100;
CDW = number of commercial driveways per mile;
INT = number of intersections per mile;
LA = lane width in ft;
RDW = number of residential driveways per mile;
SDR = percent of the 1-mile section where sight distance is restricted expressed as a whole number, thus, 10 percent = 10.0; and
SH = shoulder width in feet.

It was arbitrarily decided that the standard error of estimate must be less than half the mean number of accidents before the equation would be acceptable. There was only one equation where this ratio could not be obtained, and that was for sections of roadway in the 2,000 and 2,999 ADT range in eastern Oregon. Since this ratio was not obtainable by any method, the regression equation is shown, but its reliability is debatable. The coefficient of multiple correlation for highways in western Oregon in the 2,000 to 2,999 ADT range was so low that predictions obtained by the regression equation are of doubtful value. The remainder of the equations yield accident predictions which have reasonable accuracy.

COMPARISON OF PREDICTIONS WITH ACTUAL CASE HISTORIES

The regression equations were employed to predict the number of accidents which would be expected to occur during a 3-year period on 1-mile sections of highway in the various ADT ranges. Contiguous sections which could be combined to give sections 4 miles or more in length were used. A total of 70 percent of the sample with ADT of 3,000 or over was usable. These predictions for any given 1-mile section were then compared with the actual number of accidents which were observed for that section for the years 1952, 1953, and 1954. The percentage of error in accident predictions using these equations is presented in Figure 2. The percent error of prediction is plotted as a function of a number of contiguous miles in a section. The figure reveals a general trend for the percent of prediction errors to decrease as the length of the section increases. Unfortunately, there were not many of the longer sections (sections 8 miles or longer) so this trend was not very clear.

The average error of prediction was about 14.6 percent. It appeared that in about 50 percent of the cases it was possible to predict accidents with less than a 15 percent error. Since the predictions presented in Figure 2 were based upon the years 1952-1954 inclusive and the actual accidents are for those same years, it might be expected that the accuracy of these predictions would be somewhat exaggerated. To reduce this tendency, the regression equations based on 1952-1954 accident data were used to predict accident frequency over a 6-year period including the years 1950 through 1955. In this instance, the regression equations would be required to predict not only for the years upon which they were derived—namely 1952-1954—but also for 2 years prior to these years and 1 year following.

The percent of error in prediction is presented as a function of a number of contiguous miles in a section (Figure 3). Again, the error of prediction tends to decrease as the length of the section increases. The average absolute error of prediction for this 6-year period is 17.4 percent, and again the error of prediction is less than 15 percent in one-half of the cases. When only those sections are considered which are at least 6 miles in length, the average error of prediction

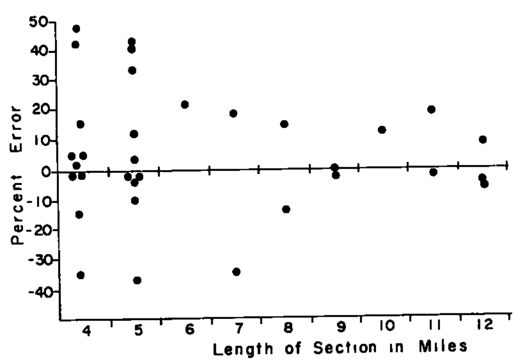


Figure 2. Percent error of total accident predictions for a 3-year period using 4 or more contiguous 1-mile sections.

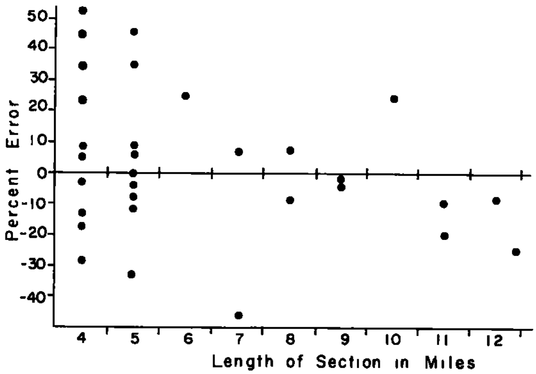


Figure 3. Percent error of total accident predictions for a 6-year period using 4 or more contiguous 1-mile sections.

for the data shown in Figure 2 is 11.6 percent, and the corresponding data for the 6-year period shown in Figure 3 is 15.2 percent. Thus, it seems that accident predictions shown in Figure 2 based on the same years for which the predictions are made are somewhat inflated with regard to accuracy, since a slightly greater order of errors in prediction was found over a 6-year period.

ACCIDENT PREDICTION FOR LOW-VOLUME ROADS

Inasmuch as satisfactory predicting equations for highway sections in the 0-999 and 1,000-1,999 ADT ranges did not result from the analysis described above, these data were made the subject of more intensive study. The preliminary analysis resulted in very low zero order correlations between accidents and the various highway elements. The extreme variation in the accident data from year to year for the same 1-mile section, and the low number of accidents generally encountered, made it appear that more satisfactory results could be obtained by combining contiguous 1-mile sections. This was done for both ADT ranges, and new coefficients of correlation were computed. Contiguous sections with identical lane width, shoulder width, and ADT were added together to give 2-mile sections. The results did not yield high coefficients of correlation, and the ratios of the standard errors of estimate to the means were regarded as too low for satisfactory accuracy.

Congestion was the only one highway element which showed any relationship to accidents in the 0-999 ADT range. Congestion was defined as the ADT divided by the capacity. For this computation, capacity was not converted to an ADT basis as the information necessary to do so was not available. It is possible that conversion to an ADT basis would have improved the relationships but this would require knowledge of hourly variations on the highways studied. Further study of this matter is recommended.

In the 1,000-1,999 ADT range, shoulder width and sight distance restriction showed the best relationships, although these relationships were not particularly high. The data for the 1,000-1,999 ADT range were again re-organized to give 3-mile sections (contiguous sections with similar characteristics were combined in groups of three). The coefficient of correlation was somewhat improved, but the ratio of the standard error of estimate to the mean was only 0.61 which was still over the desired 0.50. The regression equations are not shown in this report as it is doubtful if predictions obtained from them would have accuracy sufficient for practical use. A summary of the results of these analyses is shown in Table 5.

TABLE 5

SUMMARY TABULATION OF RESULTS OF VARIOUS ANALYSES OF SECTIONS IN LOW ADT RANGES

ADT Range	Number of Contiguous Sections	Predictors Used	Coefficient of Correlation[a]	Standard Error of Estimate	Ratio of the Standard Error of Estimate to the Mean
0 - 999	2	Congestion	0 458	2 08	0 96
1,000 - 1,999	2	SH - SDR	0 413	5 38	0.58
1,000 - 1,999	3	SH - SDR	0 464	7 55	0.61

[a]Either zero order or multiple depending on the number of predictors used

SUMMARY OF FINDINGS

1. Accident predictions are less subject to error for roadways with an ADT of 3,000 or more, than for sections with less than 3,000 ADT.

2. Personal injury accidents vary greatly by location and do not appear to be related to roadway features.

3. Accident predictions are more accurate when separate equations are used for eastern and western Oregon, thus taking into account the differences in climatic and geographic conditions which exist in the state.

4. On the rural 2-lane highways studied which perform "long-haul" functions, accidents appear to be closely related to access features (intersections and driveways); by contrast, on highways which have a primarily local service function, accidents are closely related to design features of the road itself.

5. The most important factor in the prediction of traffic accidents is the vehicle volumes on the highway. Points of access are second in importance, and design features, such as lane width, shoulder width, and sight restrictions, are third.

6. Traffic accidents on low volume roadways, particularly those on sections of highway with less than 2,000 ADT are not importantly related to any roadway element.

7. The equations presented can be used to predict total accidents on 1-mile sections of rural 2-lane highways with gravel shoulders in Oregon.

CONCLUSIONS

1. Motor vehicle accidents are directly related to vehicle volumes and certain physical features of the highway. This relationship is strong enough in the higher ADT ranges to make it possible to predict accidents on the basis of known physical features.

2. Access to the highway through driveways or intersections is directly related to accidents at all ADT levels. The number of access points is a reasonably good indicator of the number of accidents within an ADT group.

3. Although the highway design elements such as lane width, shoulder width, and sight distance restriction are related to accidents, they do not ordinarily serve as good predictors of accidents. Generally speaking, wider lanes, wider shoulders, and unimpaired sight distance result in a safer highway.

4. An analysis of the data presented in this report confirms the theory that accidents are essentially chance occurrences resulting from errors in judgment. The number of accidents increases with the number of situations presenting a change in conditions, and therefore requiring a decision on the part of the motor vehicle operator. These data confirm this theory in the following ways. (a) Accidents on low volume roads do not appear to be related to any roadway feature. (b) Accidents increase when: (1) vehicle volumes increase; (2) access points increase; (3) sight distance is impaired; and (4) the cross-section is reduced.

ACKNOWLEDGMENT

The author gratefully acknowledges the assistance rendered by Dr. Noel F. Kaestner, Statistician, Oregon State Highway Department, and Professor of Psychology, Willamette University, who provided the statistical control for the study described in this report.

Appendix A

SOURCE OF RAW DATA

The raw data employed in this investigation were derived from two major sources. The first source was obtained by three observers working in the field. The second source of data was available in the office. A detailed description of the field procedures, measurements, and recordings follows.

Field Data

The observers' task was to record shoulder and lane widths, percent sight restriction, terrain description (that is, level, rolling, or mountainous), and other pertinent remarks for each 1-mile section along a prescribed route. The cars used were specially equipped with survey speedometers which permitted identification of the exact location at which measurements and other observations were made. The survey speedometers were readable to 0.01 mile. Previously, field sheets had been prepared which provided ample space for the convenient recording of all data. A sample field sheet

Highway No 7

Terrain	ROADWAY CHARACTERISTICS					
	Width Measurement			Sight Restriction		Other Characteristics
	Lane Feet	Shoulder Feet	Location M P	Location to the nearest one-tenth of a mile	%	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
				B M.P 2 05		
R R (R)	10 11 (10)	3 4 (3)	2.05 2 61	E B E M P 3 05	85	*1 Structure* *Beg M P 2 32* *L=* 01 *W=*26 *1 Culvert* *M P 2 60* **Beyond outer edge of shoulder**
R L (L)	10 10 (10)	3 3 (3)	3.05 3 57	B M P 4 05	25	
				E E M.P 6 73	—	*Speed Zone* *40 MPH* *Omit!*
L L (L)	10 10 (10)	5 4 (5)	6.74 7.25	8 M P 7 33	20	*Check Sharp Curves* *2 Posted* IIII

Figure 4. Shoulder and roadway elements accident study.

appears in Figure 4. The material in slant print in column 7 was placed on the field sheet by the accident analysis section prior to the observers' trip to the field. It included a designation of the observers' route by consecutive 1-mile sections (column 5 of the field sheet). The number and location of structures, the location of known speed zones and reminders to check sharp curves were written in column 7. The field data are presented on the sample field sheet in bold print and were obtained in the following way.

At the beginning of each 1-mile section (column 5), the field observer would record the terrain description. The abbreviations "L" for level, "R" for rolling, and "M" for mountainous (column 1) were employed throughout. At the same location in the field the observer would also measure the lane width and shoulder width to the nearest foot and record the same (columns 2 and 3). After making these measurements and recordings, the observer would proceed along the 1-mile section taking note of the terrain and any potential speed restriction factors in the 1-mile section. Somewhere further on, usually in the middle of the section, the driver again made shoulder and lane measurements and also recorded the abbreviated description of the terrain. In this manner at least two measurements were taken of the lane width and shoulder width within each mile. The mile post location of the first and second and any other points of measurement within the 1 mile were also recorded (column 4). Total pavement width (both lanes) and both left and right shoulders were measured at each stop. The shoulder width was taken as that area which was obviously safe or practical for shoulder use. Generally, the distance between the outer edge of the pavement and the inner edge of the ditch, or in some cases merely stable roadside surface, satisfied this criterion. Before leaving any 1-mile section, the driver used the above measurements to estimate a more representative index of lane width, shoulder width, and terrain for the section. These best estimates appear in circles in columns 1, 2, and 3 for each 1-mile section. Since the best estimates were based on the mile considered as a whole, no location measurement for them appears in column 4.

In addition to the above measurements and recordings, the driver kept a continuous record of the presence or absence of sight restriction. The 0.1-mile divisions appearing in column 5 were utilized in recording these data. As the observer proceeded through a section, special notations were made concerning the location of the beginning and end of unrestricted sight distance (1,500 ft of pavement visible). When the observer approached a section with restricted sight distance, he watched the road behind him to find the beginning point of unrestricted sight distance for vehicles traveling in the opposite direction. Upon reaching that point, its location was noted in column 5 on the field sheet. The letter "E" was used to designate this point. The beginning of sight distance restriction for the observer's direction of travel was 1,500 ft (0.3 mile) behind the point E. As he proceeded through the section with restricted sight distance, he selected a point which appeared to offer the beginning of unrestricted sight distance for his direction of travel and recorded a "B" (correct to the nearest 0.1 mile) in column 5. The end point of pavement visibility for vehicles traveling in the opposite direction was 1,500 ft ahead of the point designated by B.

Upon the field observer's return to the office, he blanked out (indicated by the vertical lines in column 5) any 0.1-mile sections in either direction of travel that did not have the required 1,500 ft sight clearance. In this manner, it was possible to determine in 5-percent steps the amount of sight restriction present for each 1-mile section, and these determinations appear in column 6.

Concurrently with the above measurements and estimates, the field observer measured the structures and checked the number of curves when these were indicated in column 7 (slant print). The length of the structures measured in hundredths of a mile and the width of structures measured to the nearest foot, were recorded below the indicated structure. In a similar way, the observer's tabulation of the number of sharp curves was recorded. In those cases where a culvert was indicated, the observer

Hwy No	ADT in Hundreds	Beginning Mile Post	Width		Terrain	Sight Restriction (Per Cent)	Structures			Number of Curves	DRVWY		Number of Intersections	Capacity Index	Accidents						Congestion Index
			Lane	Shoulder			Length	Width	Number		Commercial	Residental			Non Intersectional			Intersectional			
															Fatal	Non-fatal	Property Damage	Fatal	Non-fatal	Property Damage	
35	35	00030	10	03	1	100	01	22	1	10	03	00	02	315	0	06	16	0	0	02	1100
35	31	00130	10	04	1	80	00	00	0	08	05	00	01	320	1	06	24	0	1	03	0970
35	31	00230	11	03	0	100	00	00	0	09	00	00	02	355	0	06	19	0	1	02	0870

Figure 5. Roadway elements study.

would note whether the outer edge of the culvert infringed upon the natural shoulder width for that portion of the 1-mile section. If the culvert did restrict the shoulder width at that point, its length and width were also recorded.

The data on the field sheets were transcribed in the office onto code sheets (Figure 5). This field data appears on the sample code sheet in bold print. The terrain description presented on the field sheet in terms of single letter abbreviations was transformed into a numerical code wherein level, rolling, and mountainous were designated by 0, 1, and 2, respectively. The other data appearing in slant print on the code sheet were obtained in the office.

Office Data

An estimate of the ADT for each 1-mile section was developed from the data of traffic volume tables for 1953. No 1-mile section was included in this study which had more than a 10 percent difference in ADT throughout the mile. In addition to the ADT values, accident data and driveway data were available in the accident analysis section of the traffic engineering division. This section provided accident data for each 1-mile stretch in the sample of 1,374 sections.

The number of accidents per year in terms of personal injury, property damage, and their total were placed on the code sheets mentioned above. These included intersectional as well as non-intersectional accidents. The completed code sheet provided the following information for each 1-mile section: terrain, lane width, shoulder width, sight restriction, ADT, and personal injury, property damage, and total accidents for each year from 1952 to 1954.

Appendix B

ANALYSIS OF NON-INTERSECTIONAL ACCIDENTS

A considerable amount of time was spent in developing a method of analysis. Several efforts to derive useful predictive devices were made in this particular study prior to those finally employed. Some of the findings in the earlier analyses are of interest and, therefore, the history of the various analyses is presented here.

All of the analyses described in this appendix dealt with non-intersectional accidents. Preliminary studies had shown that the high variability of personal injury or fatal accidents precluded the possibility of predicting these accidents individually. They did not show strong relationships to individual highway elements and their occurrences were so random and so few that a sufficient body of data could not be developed to permit a thorough analysis. Therefore, personal injury and fatal accidents were combined with accidents which resulted in property damage only. This total was used in all of the following analyses. The distribution of non-intersectional accidents is shown in Figure 6.

In the first approach to the problem of accident prediction, the relationship between accidents and congestion was examined. The congestion of the roadway was expressed as the ratio of the highways ADT to its capacity (for the non-intersectional part of the section). Thus, congestion reflects the effect of the actual usage of a roadway relative to its theoretical traffic carrying ability.

In these original analyses, the highway sections were not grouped in ADT ranges. The relationship between congestion and accidents was reasonably strong (the coefficient of correlation was 0.725). However, the ratio of the standard error of estimate to the mean was 0.83. When commercial driveways were combined with congestion, the coefficient of correlation improved somewhat as did the ratio of the standard error of estimate to the mean. A similar slight improvement was realized when residential driveways were added. These findings are summarized in Table 6. None of the relationships showed a sufficiently low ratio of the standard error of estimate to the mean for accurate predictions.

Another analysis was undertaken which investigated the relationship between ADT and accidents. This relationship had been found to be very strong in the previous analysis, and it was thought that satisfactory prediction equations could be developed based on ADT plus commercial and residential driveways. This analysis was similar to that

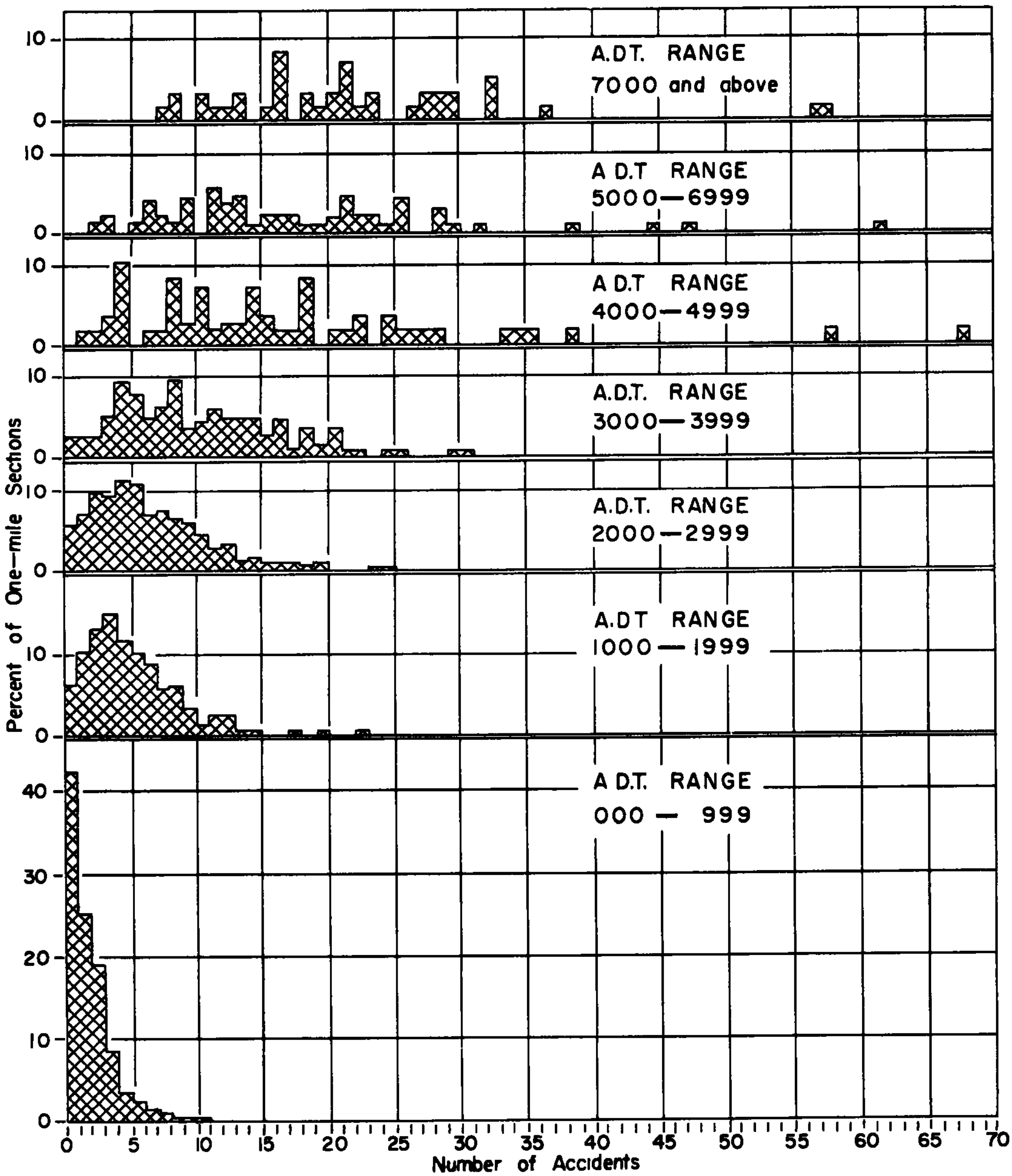


Figure 6. The percentage distribution of 1-mile sections by number of non-intersectional accidents for various ADT ranges.

TABLE 6

SUMMARY TABULATION OF RESULTS OBTAINED FROM ANALYSES USING UNGROUPED DATA FOR NON-INTERSECTIONAL ACCIDENTS WITH NO GEOGRAPHICAL BREAKDOWN

Predictors Used	Coefficient of Correlation[a]	Standard Error of Estimate	Ratio of the Standard Error of Estimate to the Mean
ADT	0 700	5.20	0.86
ADT-CDW	0.751	4.81	0.80
ADT-CDW-RDW	0.761	4.72	0.78
Congestion	0 725	5 02	0.83
Congestion-CDW	0 765	4.69	0.78
Congestion-CDW-RDW	0 774	4.61	0.76

[a] Either zero order or multiple depending on number of predictors

described above and is also summarized in Table 6. Once again, satisfactory predictions did not appear possible because of the high ratios of the standard errors of estimate to the means.

It appeared that it would not be possible to develop satisfactory predicting equations without grouping the data in ADT ranges. When this was done, the coefficients of correlation were somewhat less than those obtained in the earlier analyses, but the ratios of the standard errors to the means were considerably increased.

Originally congestion was used alone, then commercial and residential driveways were added. Ultimately the three or four best predictors observed in the zero order correlations were combined. These three or four individual elements frequently gave results as satisfactory as those obtained using congestion and driveways. Since congestion involves a fairly complicated computation requiring knowledge of each of five individual highway elements, it seemed advisable to use the three best predictors in the equations. This requires considerably less field investigation, and yields accuracy as great or greater than that resulting from the more complicated computations. The results of these analyses are summarized in Table 7.

When the final regression equations had been computed, accident predictions for various representative sections were computed and checked against actual accident history for these sections. While the results were generally encouraging and within reasonable limits of accuracy, there were several cases of extreme variance. An examination of the individual cases led to the conclusion that regression equations based on all the data were not satisfactory for sections of highway in all portions of the state. It was decided that the data should be further divided on an east-west basis.

These two sections of Oregon have great differences in climate and geography as well as in travel characteristics. Cities in eastern Oregon are smaller and farther apart than those in western Oregon, thus requiring longer travel distances between population centers with less commercial and residential development along the route. Most highways in eastern Oregon perform long haul functions, whereas many highways in western Oregon are used for farm-to-market trips or short trips between cities. When the data were divided geographically and analyzed for each ADT range in the two geographic divisions, better results were obtained when predictions were compared to actual case histories.

Therefore, this type of analysis was used for total accident predictions as described in the text.

TABLE 7

RESULTS OF ANALYSIS OF NON-INTERSECTIONAL ACCIDENTS WITH SECTIONS GROUPED IN ADT RANGES

ADT Range	Section of Oregon	Predictors Used	Coefficient of Correlation[a]	Standard Error of Estimate	Ratio of the Standard Error of Estimate to the Mean
3,000 - 3,999	All	Congestion	0 590	5 08	0 51
	All	Cong -CDW-RDW	0.668	4.67	0 47
	All	SDR-CDW-SH	0.664	4 70	0.47
	Western	SDR-SH-CDW+LA	0.913[b]	2.77	0.24
3,000 and over	Eastern	CDW-RDW-INT-SH	0.711[b]	3.15	0.43
4,000 - 4,999	All	Congestion	0 427	10 97	0.70
	All	Cong +CDW+RDW	0.610	9.62	0 62
	Western	CDW-RDW+SH	0 670[b]	9.00	0.58
5,000 - 6,999	All	Congestion	0.142	10.75	0.63
	All	Cong. +CDW+RDW	0.665	8.11	0 47
	Western	CDW+RDW+SH	0 670[b]	8.06	0.47
7,000 and over	Western	Congestion	0.313	10.24	0.47
	Western	Cong. +CDW+RDW	0.388	9.93	0.44
	Western	ADT+RDW+SH	0.501[b]	9.32	0.41

[a] Either zero order or multiple, depending on the number of predictors used.
[b] These combinations were used in the regression equations shown in the text.

The regression equations for non-intersectional accidents are as follows:

For highways in western Oregon:

1W when the ADT is between 3,000 and 3,999

$$A = 7.69 + 0.03\ SDR - 0.21\ SH + 0.10\ CDW - 0.41\ LA$$

2W when the ADT is between 4,000 and 4,999

$$A = 8.51 - 0.58\ SH + 0.23\ CDW + 0.004\ RDW$$

3W when the ADT is between 5,000 and 6,999

$$A = 4.84 + 0.31\ RDW + 0.19\ CDW - 0.12\ SH$$

4W when the ADT is 7,000 or more

$$A = 3.75 - 0.24\ SH + 0.26\ RDW + 0.16\ ADT$$

For highways in eastern Oregon:

1E when the ADT is between 3,000 and over

$$A = 1.04 + 0.23\ CDW + 0.11\ RDW + 0.08\ INT + 0.12\ SH$$

in which

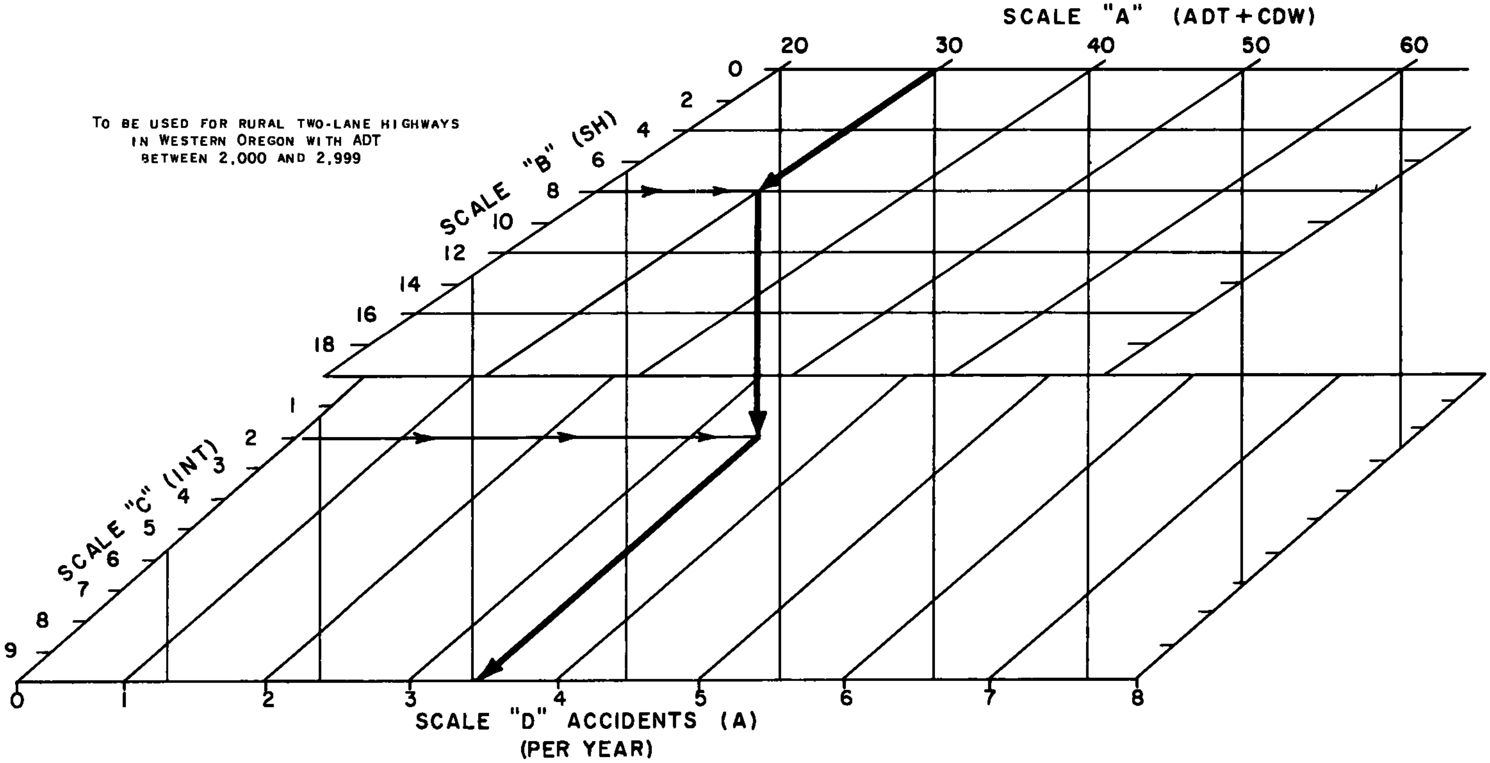
A = total non-intersectional accident experience for a 1-mile section during a 1-year period;
ADT = number of average daily traffic divided by 100;
CDW = number of commercial driveways per mile;
INT = number of intersections per mile;
LA = lane width in feet;
RDW = number of residential driveways per mile;
SDR = percent of the 1-mile section where sight distance is restricted. expressed as a whole number, thus 10 percent = 10.0; and
SH = shoulder width in feet.

Appendix C

NOMOGRAM SOLUTIONS

Calculation of accident predictions can be simplified considerably by the use of nomograms which have been prepared for each of the 7 equations. They permit rapid graphical solutions giving satisfactory accuracy. The equations were modified in some cases by combining elements with like coefficients or substituting averages for certain elements with very low coefficients. The loss of accuracy resulting from these modifications is negligible.

The nomograph solutions for the various equations are shown in Figures 7 through 14.



1 ENTER SCALE A WITH THE SUM OF ADT (IN HUNDREDS) AND COMMERCIAL DRIVEWAYS

2 FOLLOW PARALLEL TO SCALE B TO INTERSECTION WITH SHOULDER WIDTH

3 DROP VERTICAL FROM THIS POINT TO INTERSECTION WITH NUMBER OF INTERSECTIONS (SCALE C)

4 FOLLOW PARALLEL TO SCALE C TO INTERSECTION WITH SCALE D

5 READ ACCIDENTS DIRECT FROM SCALE D

EXAMPLE

ADT	2,500
CDW	5
SH	8
INT	2
A	3 5

EQUATION 1W, MODIFIED A = 0 11 (ADT CDW) - 0 16SH + 0 28INT

Figure 7. Nomogram for the solution of Equation 1W.

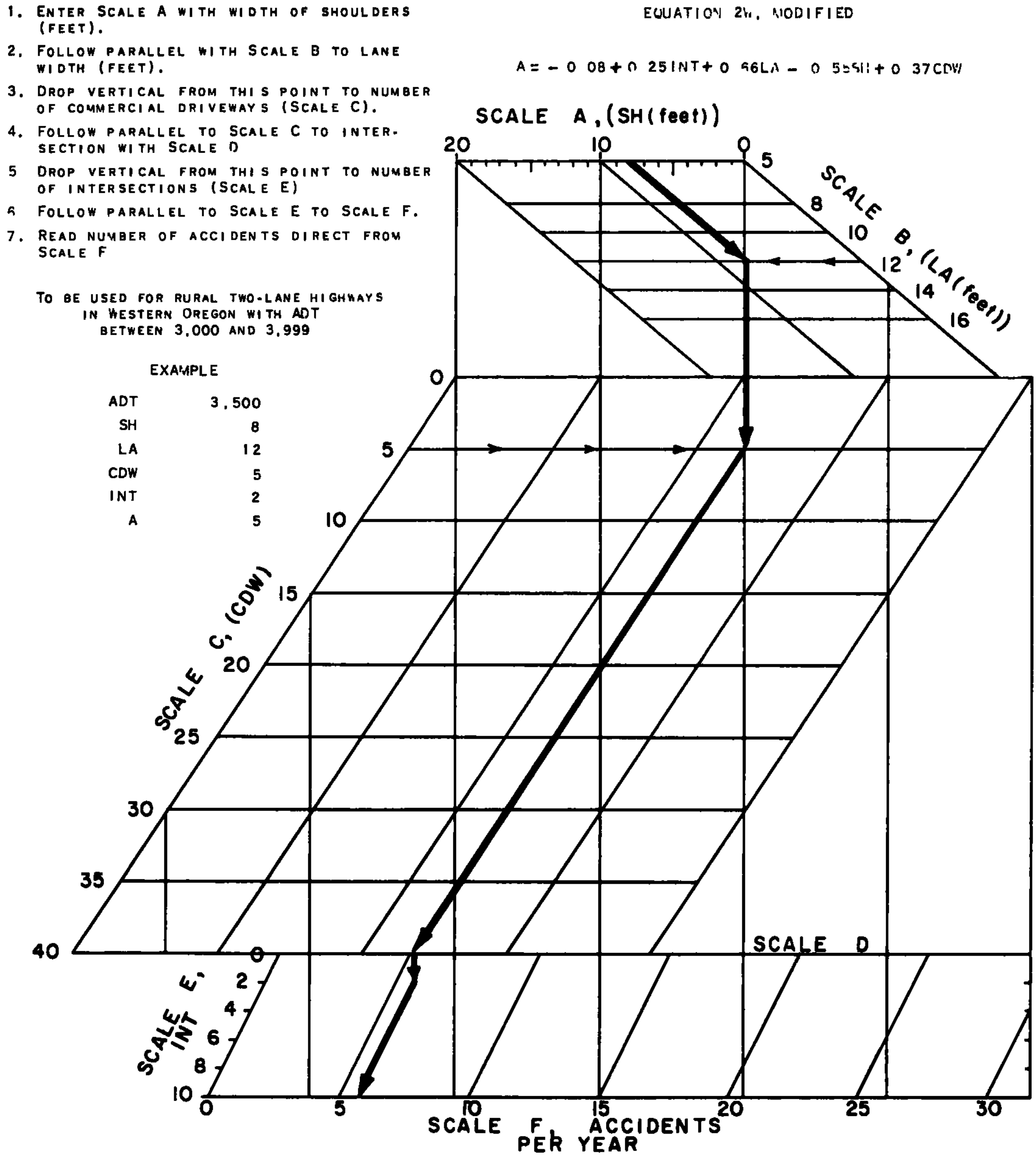


Figure 8. Nomogram for the solution of Equation 2W.

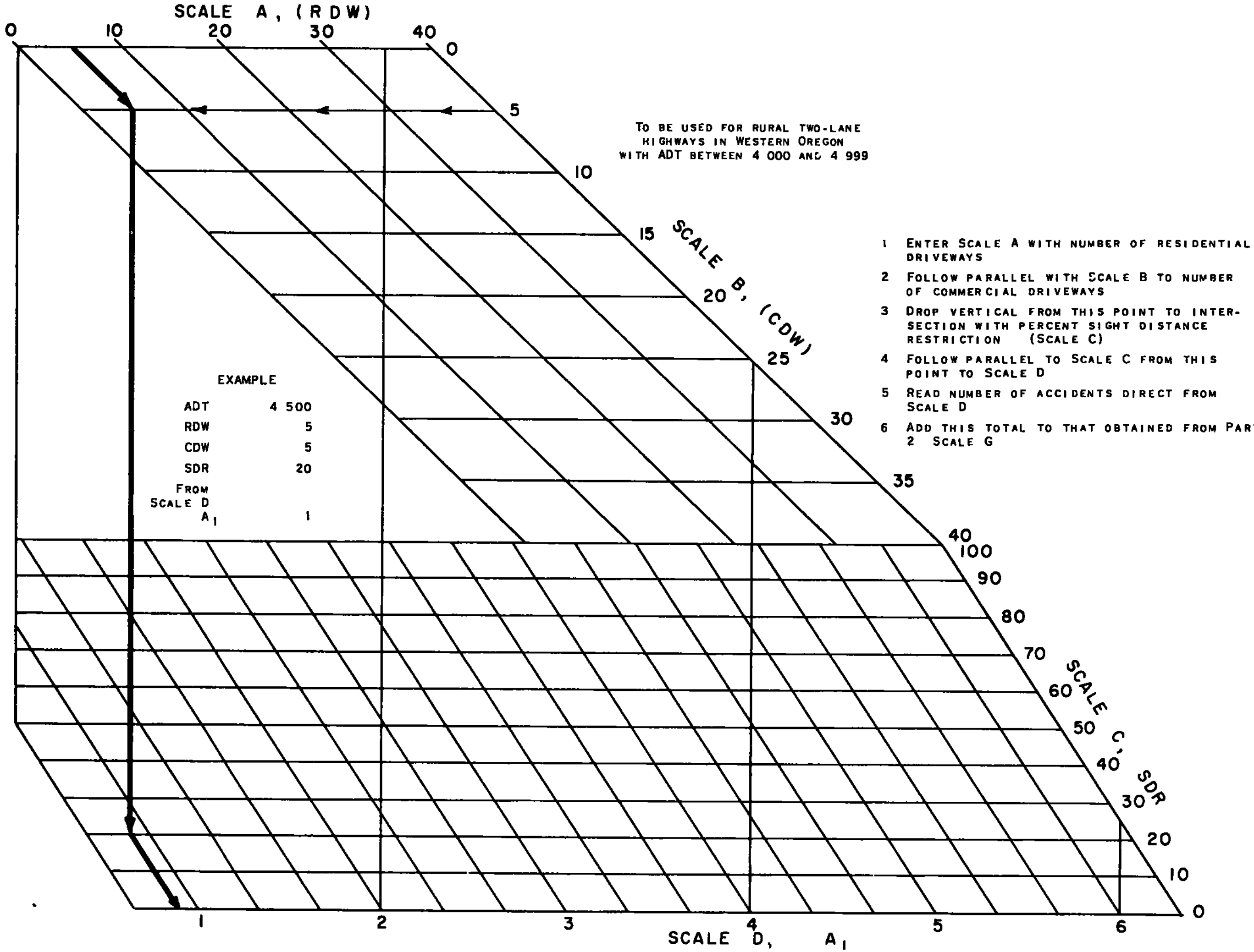


Figure 9. Nomogram for the sloution of Equation 3W, Part 1.

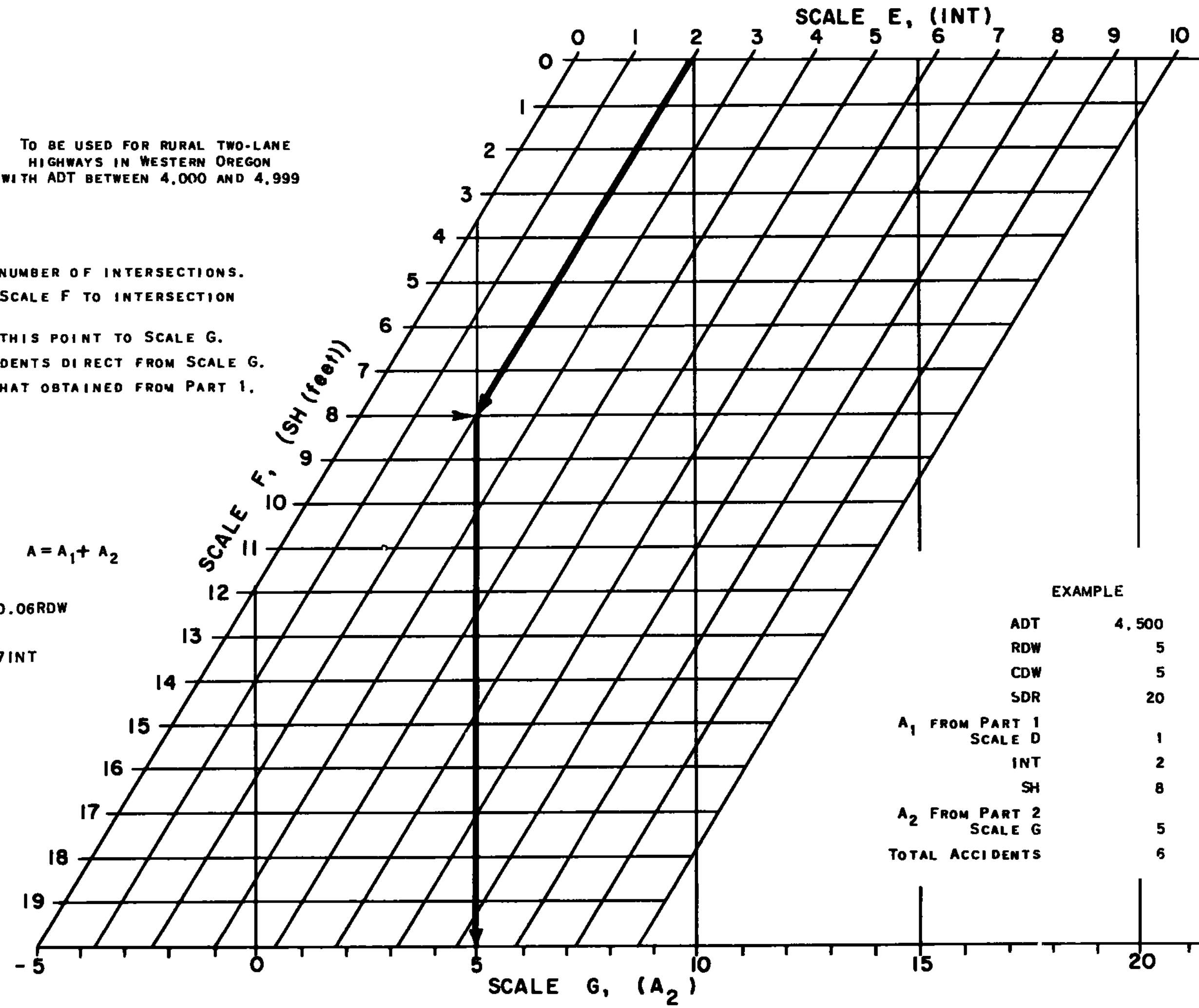
To be used for rural two-lane
highways in Western Oregon
with ADT between 4,000 and 4,999

1. Enter Scale E with number of intersections.
2. Follow parallel to Scale F to intersection with shoulder width
3. Drop vertical from this point to Scale G.
4 Read number of accidents direct from Scale G.
5. Add this total to that obtained from Part 1, Scale D.

EQUATION 3W, MODIFIED $A = A_1 + A_2$

$A_1 = 0\ 01SDR + 0.07CDW + 0.06RDW$

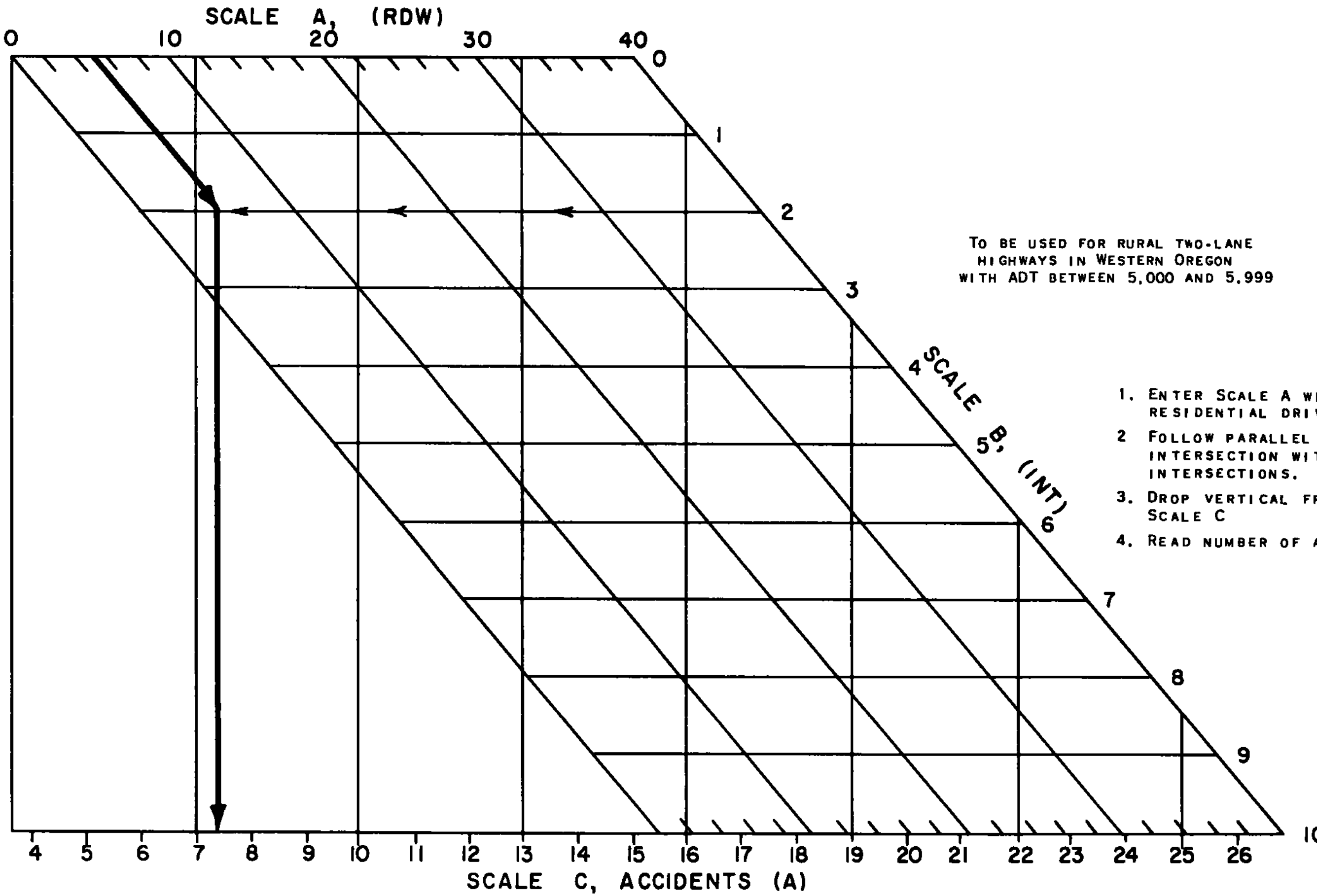
$A_2 = 7\ 33 - 0\ \text{o}1SH + 1\ 37INT$



EXAMPLE

ADT	4,500
RDW	5
CDW	5
SDR	20
A_1 From Part 1 Scale D	1
INT	2
SH	8
A_2 From Part 2 Scale G	5
Total Accidents	6

Figure 10. Nomogram for the solution of Equation 3W, Part 2.



TO BE USED FOR RURAL TWO-LANE HIGHWAYS IN WESTERN OREGON WITH ADT BETWEEN 5,000 AND 5,999

1. ENTER SCALE A WITH THE NUMBER OF RESIDENTIAL DRIVEWAYS
2. FOLLOW PARALLEL TO SCALE B TO THE INTERSECTION WITH THE NUMBER OF INTERSECTIONS.
3. DROP VERTICAL FROM THIS POINT TO SCALE C
4. READ NUMBER OF ACCIDENTS FROM SCALE C

EXAMPLE

ADT	5,500
RDW	5
INT	2
A	7

EQUATION 4W, MODIFIED $A = 3.70 + 0.28RDW + 1.17INT$

Figure 11. Nomogram for the solution of Equation 4W.

To be used for rural two-lane highways in western Oregon with ADT between 6 000 and 5 999

1. Enter Scale A with number of residential driveways
2. Follow parallel to Scale B to intersection with number of intersections
3. Drop vertical from this point to intersection with ADT (Scale C)
4. Follow parallel to Scale C to Scale D
5. Drop vertical from this point to intersection with number of commercial driveways (Scale E)
6. Follow parallel to Scale E from this point to Scale F
7. Read number of accidents from Scale F

EQUATION 5W, MODIFIED A = − 10 67 + 0 33ADT

+0 17CDW + 0 48RDW +, 0 49INT

EXAMPLE

ADT	7,000
RDW	5
INT	2
CDW	5
A	10

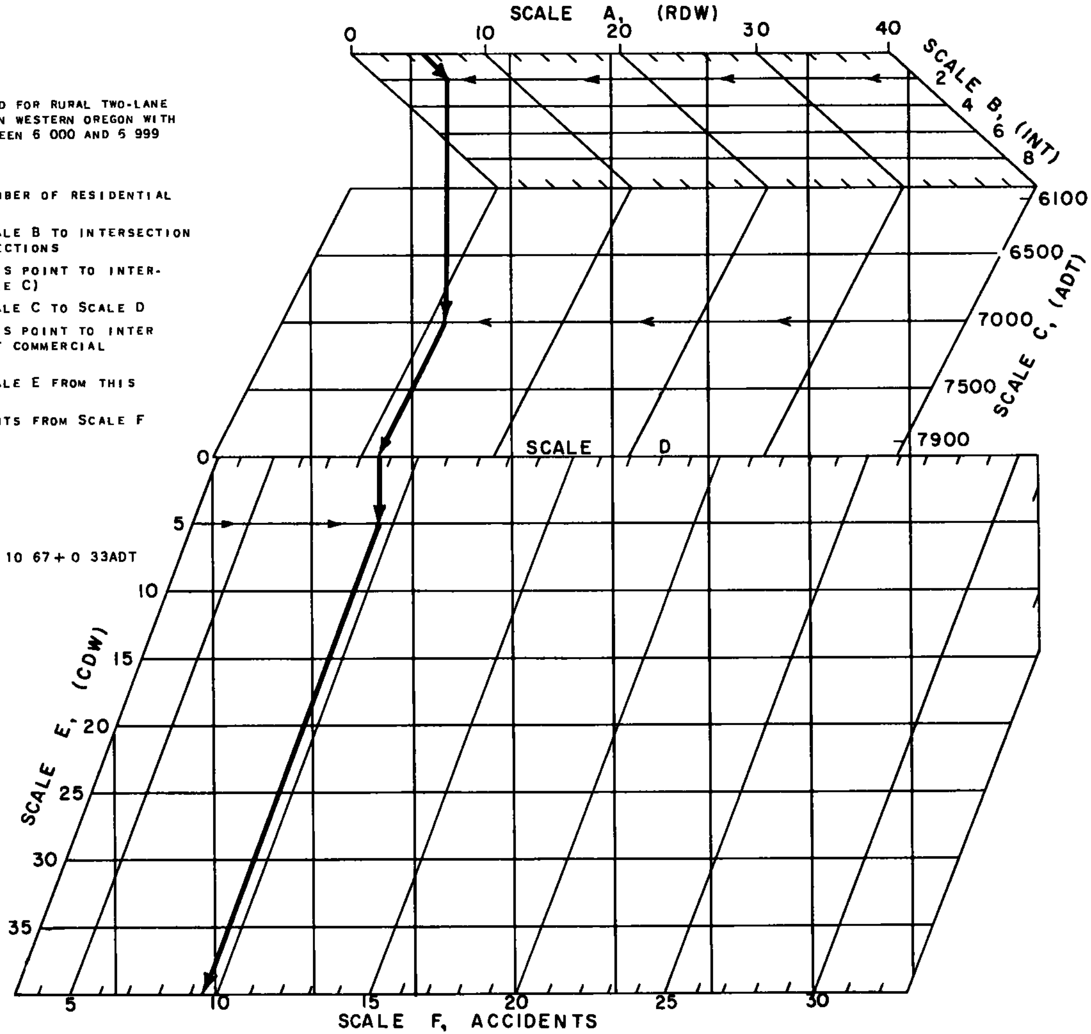
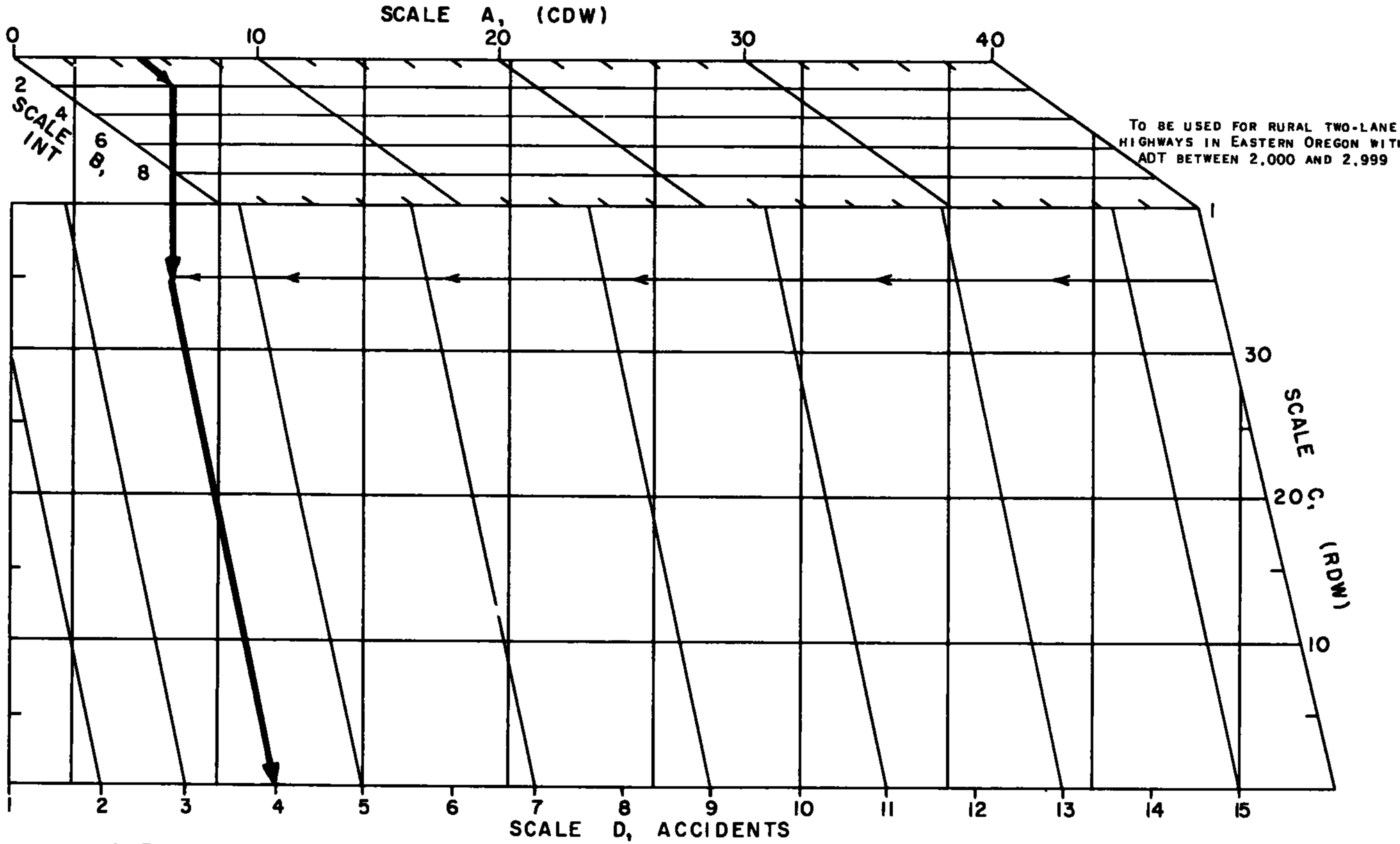


Figure 12. Nomogram for the solution of Equation 5W.



1 Enter Scale A with the number of Commercial Driveways

2 Follow Parallel to Scale B to an intersection with the number of intersections.

3 Drop vertical from this point to an intersection with the number of residential driveways (Scale C)

4 Follow parallel to Scale C to Scale D

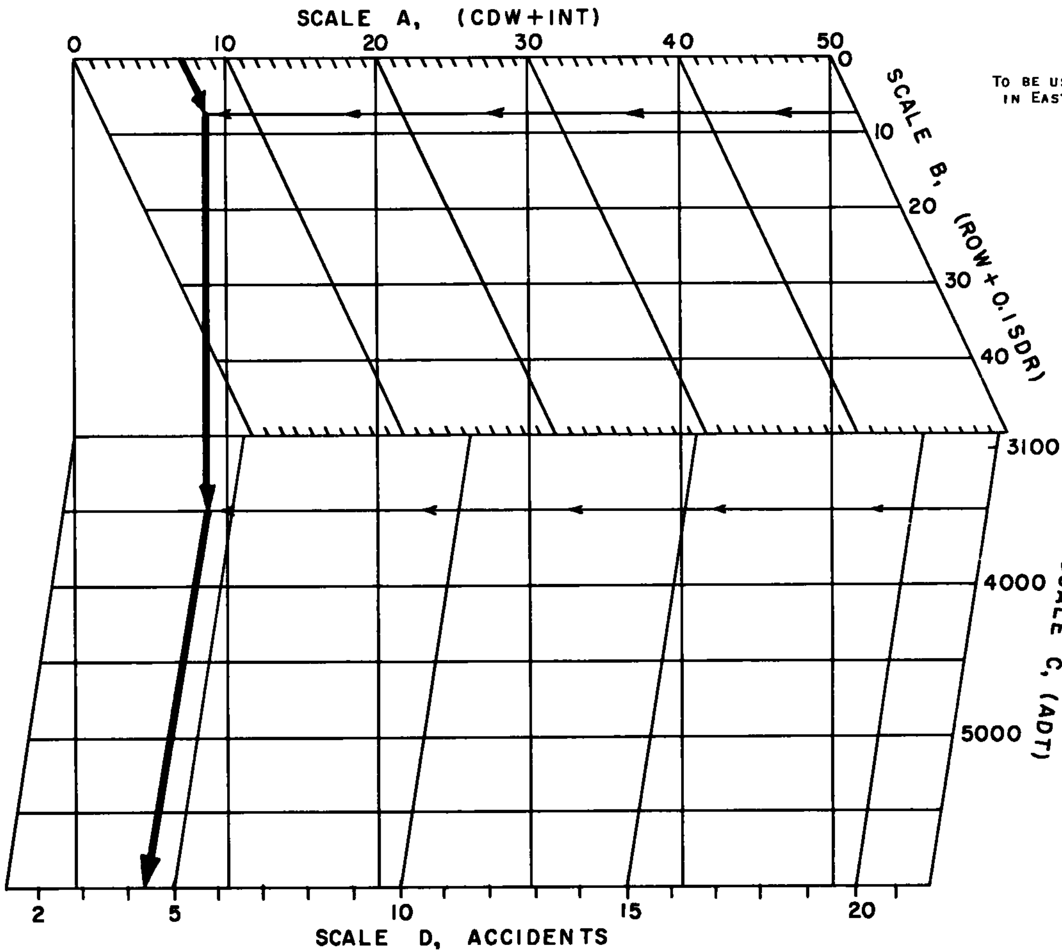
5 Read number of accidents from Scale D

EXAMPLE

ADT	2,500
CDW	5
INT	2
RDW	5
A	4

EQUATION 1E MODIFIED $A = 0.95 + 0.28CDW + 0.24INT + 0.04RDW$

Figure 13. Nomogram for the solution of Equation 1E.



TO BE USED FOR RURAL TWO-LANE HIGHWAYS IN EASTERN OREGON WITH ADT ABOVE 3,000

1 ENTER SCALE A WITH SUM OF COMMERCIAL DRIVEWAYS AND INTERSECTIONS.
2. FOLLOW PARALLEL TO SCALE B TO INTERSECTION WITH SUM OF RESIDENTIAL DRIVEWAYS PLUS 0.1 TIMES THE PERCENT OF SIGHT RESTRICTION (SCALE B).
3. DROP VERTICAL TO INTERSECTION WITH ADT, SCALE C.
4 FOLLOW PARALLEL TO SCALE C FROM THIS POINT TO SCALE D.
5. READ NUMBER OF ACCIDENTS DIRECT FROM SCALE D

EXAMPLE

ADT	3,500
CDW	5
INT	2
RDW	5
SDR	20
A	4

EQUATION 2E, MODIFIED

A = 0 26 + 0 05ADT + 0 33(CDW INT) + 0 08(RDW 0 1SDR)

Figure 14. Nomogram for the solution of Equation 2E.