The Relationship Between Accident Data and the Width of Gravel Shoulders in Oregon[1]

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The investigation described herein represents research by the Oregon State Highway Department to understand the effect of width of graveled shoulders on nonintersectional accidents. Probably the most important finding in this investigation was that accident frequency was not related to shoulder width for the lower ADT highways (ADT less than 3600). The finding that shoulder width did not affect accident occurrence was supported by the fact that accident occurrence did not seem to be related to any other roadway feature controlled in this study (e. g., commercial and residential driveways, lane width, curves, terrain, or sight restrictions).

The second important finding, this time positive in nature, was a tendency toward a reduction in accidents as shoulder width increased in the higher ADT ranges. This tendency was statistically reliable for total accidents and property damage accidents in the 3600 to 5500 ADT range. This observed inverse relationship between shoulder width and accident frequency concurs with the implicit assumptions of highway designers who have felt that something must be done to alleviate congestion on higher ADT 2-lane roadways. In practice, one of the things that has been done was widening of the shoulders. On the basis of the results of this study, it appears reasonable to suspect that these shoulder improvements actually were helpful in this volume range on 2-lane rural tangents.

Speed checks were available for many of the sections in the 3600 to 5500 ADT range as well as in the 5600 to 7500 ADT range. Analysis of the speed data as a function of shoulder width indicated that no significant relationship existed between shoulder width and speed in the 3600 to 5500 ADT range; whereas a highly positive relationship emerged between speed and shoulder width in the 5600 to 7500 ADT range. The results of these analyses might have accounted for the insignificance of the relationship between shoulder width and accidents.

It appeared that the contribution of shoulder width to accident occurrence taken by itself was generally slight on the lower volume roads (ADT less than 3600). On higher volume roads (3600 to 7500 ADT) wide shoulders tended to reduce accidents, especially property damage and total accidents. However, when there was a significant increase in vehicle speed with wide shoulders as was found in the 5600 to 7500 ADT range, this tendency for a reduction in accidents with wide shoulders fell short of statistical significance. In line with the findings of Belmont's California study,[2] the

[1] Prepared for Project Committee No. 3, "Effect of Highway Shoulders on Accidents," Department of Traffic and Operations, Highway Research Board.
[2] "As shoulder width increases, drivers may gain an unjustified feeling of security. Speed may increase, with an attendant increase in accident rates" (number of accidents).

possibility arises that personal injury accidents were affected by shoulder width in a somewhat different way than was the case for property damage accidents. At the time of this writing, the cause of this discrepancy between the two types of accidents, namely, personal injury and property damage accidents, is unknown—unless paved shoulders account for it.

● THE investigation described herein represents research by the Oregon State Highway Department in cooperation with Project Committee No. 3 of the Department of Traffic and Operation, Highway Research Board, to understand the effect of width of graveled shoulders on non-intersectional accidents. The purpose of Project Committee No. 3, organized in 1947, was to examine the influence of shoulders on traffic operations.

Personal injury, property damage, and total accidents were analyzed for the years 1952 through 1954. In order to isolate the contribution of shoulder width itself, statistical and/or field controls were used to eliminate the effects of the other physical factors contributing to accident occurrence. The factors eliminated were terrain, curves, sight restrictions, lane width, and commercial and residential driveways. The effect of traffic volume was also controlled by evaluating the accident-shoulder relationship within each of five arbitrarily defined average daily traffic (ADT) ranges.

BACKGROUND

In September of 1947, Project Committee No. 3 of the Department of Traffic and Operation, Highway Research Board, called its first meeting. The purpose of this committee was to examine the influence of shoulders on traffic operations. Essentially straight and level rural 2-lane tangents were to be the focus of attention. To determine the effectiveness of shoulders for traffic operations, the following criteria were decided upon: speed, transverse placement of vehicles, and accidents. Taragin and Eckhardt (*1*) have already investigated the effect of shoulder width on the speed and transverse placements of moving vehicles.

Several recent studies bear on the third criterion, accidents. Raff (*2*) found "no indication that shoulder width, considered alone, has any bearing on the accident rates." The data he analyzed were supplied by 15 states and were based on 1941 accident records on rural sections of the interstate highway system. Subsequently, Belmont (*3*), using California accident data of 1948, observed that "paved shoulders six feet wide were safer than narrower shoulders and, also at the volumes over 5,000 vehicles per day, safer than wider shoulders." These results were explained in terms of insufficient clearance between passing vehicles on paved shoulders narrower than 6 feet, less emergency maneuverability, and less adequate off-the-road parking. Wider shoulders were considered to have serious disadvantages in congested traffic where they may be used for unsafe passing on the right. In a later investigation by Belmont (*4*), "personal injury" accident rate tended to increase with paved shoulder width except at traffic volumes below 2000 vehicles per day where the trend may be reversed. In this study, accident data were restricted to the injury type for the years 1951 and 1952. In both of Belmont's investigations, only tangents with paved shoulders were included.

These findings indicate that the precise relationship between shoulder width and accidents is still unclear. In one case, shoulder width is found to be unrelated to accidents (*2*). In another instance, shoulders of intermediate width are found to be safest (*3*). Still other evidence points to a direct relationship between shoulder width and injury accidents (*4*). As noted by Belmont (*4*), this divergence in the findings may be attributable in part to the type of accident reported and to the adequacy of the reporting itself. Furthermore, the type of shoulder, whether gravel or paved, may be exerting a force in producing the discrepant results. Other uncontrolled factors, such as driveways, may have been influential in creating these controversial results. In any event, it would appear inadvisable to predict the effect of shoulder width on accidents under conditions different from those reported above.

The investigation described below represents research by the Oregon State Highway Department to understand the effect of shoulder width on non-intersectional accidents occurring on primary state highways with 2-lane tangents during 1952 through 1954 in Oregon. Only accident data from sections with gravel shoulders were included in this analysis. Because Oregon law requires prompt reporting of all accidents regardless of their severity or extent of damage, relatively complete data were available for property damage as well as injury accidents. Extensive field and statistical controls were designed to eliminate the influence of all factors, except shoulders, on accident occurrence. Factors controlled were terrain, curves, sight restriction, lane width, commercial and residential driveways, and traffic volume. Control of these conditions was essential in order to definitely establish the relationship between each of several accident types and shoulder width taken alone.

PROCEDURES

Field Work

The shoulder-width data were obtained in the field on routes chosen to include only rural 2-lane Oregon state primary highways with gravel shoulders. Any sections which had new construction since 1952, the first year for which accident data were used in the analysis, were eliminated. The observers recorded measurements of lane width, shoulder width, and sight restriction, together with terrain description, on the field sheets. A detailed description of the field procedure along with a sample field sheet appears in Appendix A.

The information derived from the field work was employed to control the effect of several factors which otherwise might distort the effect of shoulders on accident occurrence. First, only those 1-mile sections were included in this investigation which had 30 percent or less sight restriction. A 1-mile section with only 30 percent sight restriction could have at most only one point beyond which the driver could not see and once the driver reached that point the remainder of the section would be clearly visible. By this means the influence of terrain on accidents was in effect controlled, since the exclusion of sections with sight restrictions greater than 30 percent virtually eliminated the sections with rolling and mountainous terrain. The second field control was that of lane width. No accident data were included for highway sections which had lanes less than 10 feet wide. The remaining variation in lane width was statistically controlled. The bulk of the sections had 10, 11, or 12-foot lanes. In summary then, only those 1-mile sections of rural 2-lane roads which met the following field conditions were included in this investigation:

1. Gravel shoulders.
2. Sight restriction of 30 percent or less.
3. Ten foot or wider lanes.
4. Without speed zones or conditions which tend to reduce speed.
5. Essentially straight and level.

Of the 1391 miles of highway surveyed, 344 1-mile sections qualified for further analysis and control. All data gathered, however, were retained for a later "Roadway Elements vs. Accidents Study."

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 1952 through 1954 were employed. Fatal and non-fatal accidents were pooled at the onset because of the relatively infrequent occurrence of fatalities. No distinction between fatal and non-fatal accidents was observed in the subsequent analyses and interpretations. Also, no attempt to establish year-to-year accident trends was made. Instead, a 3-year summation of all personal injury (fatal and non-fatal) accidents and a similar total of all property damage accidents was made, thus producing two types of accident totals. A third total emerged when total personal injury accidents and total property damage accidents were combined. In this way, three accident totals were associated with each 1-mile section. Each total was based on a 3-year accident record for the particular 1-mile section concerned. All accident totals were developed on the Department's IBM computing equipment.

Traffic Volume Data

The average daily traffic (ADT) data were taken from the Traffic Volume Tables for 1953 published by the Oregon State Highway Department (*5*). The 1953 data correspond to the mid-year of the 3-year accident data employed. An ADT value was assigned to each 1-mile section. If more than a 10 percent volume change occurred within a given mile section, the section was excluded from further consideration.

Because there is generally a very real relationship between accidents and traffic volume, it was necessary to control the effect of average daily traffic on accidents. This control was especially important because a relationship between shoulder width and average daily traffic appeared likely. This correspondence frequently appears at the higher volumes where road improvements are often designed to relieve the stress of excessive traffic. Widening of the shoulders is one form of such improvement. Thus, wide shoulders tend to accompany higher volumes. In this way, a positive relationship between accidents and shoulder width would merely be a reflection of the direct correspondence between accidents and average daily traffic.

The control of the disruptive influence of traffic volume on accident data was accomplished in two ways. First, the accident-shoulder data were arbitrarily subdivided according to average daily traffic ranges. The result of this subdivision was the five groupings shown as follows:

THE DISTRIBUTION OF ONE-MILE SECTIONS BY ADT RANGE

	ADT Range					
	600–1500	1600–2500	2600–3500	3600–5500	5600–7500	Total
Sample size	67	134	80	39	24	344
Percent of sample	19.5	39.0	23.2	11.3	7.0	100.0

It is readily apparent that the bulk of the data available for analysis came from the low ADT roads—3500 ADT and lower. By studying the relationship between shoulder width and accidents within each ADT group, the effects of ADT on accident occurrence were roughly controlled.

The above control procedure is most likely to be efficient when the ADT range within each group is relatively small. However, in order to get samples of a reasonable size at the higher ADT's, a wider volume range was demanded. Thus, the two highest ADT groups incorporated a range of 2000 vehicles (i. e., 3600–5500 ADT and 5600–7500 ADT). To eliminate the remaining variation in ADT within these groupings, a second type of control was required. This second control was a statistical technique which will be described later. The effect of this technique was to remove any possible influence that average daily traffic (ADT) may have had on the accident-shoulder relationship.

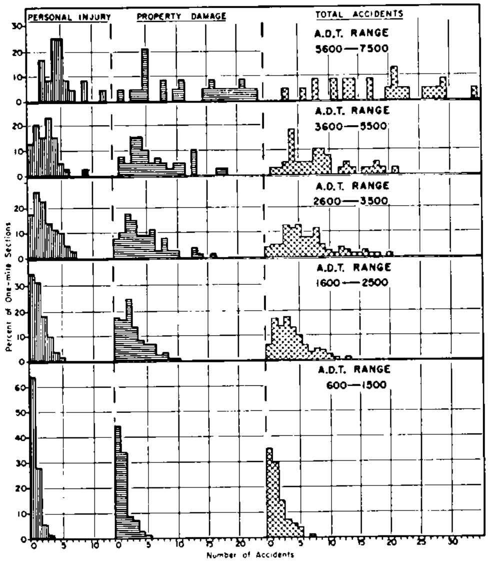

Figure 1. The percentage distribution of accident frequency as a function of average daily traffic.

DESCRIPTION OF SAMPLE

Accident Data

The percent of accidents for the various ADT groups is shown in Figure 1. The number of accidents per mile section appears on the abscissa and the ordinate represents the percent of 1-mile sections having these accident frequencies. Average daily traffic differences are shown in successive vertical sections of the figure. Personal injury, property damage, and total accidents represent the types of accidents studied and appear in Figure 1 from left to right, respectively.

Examination of Figure 1 reveals that the percent of sections having very few accidents decreased as the ADT level went up; in other words, as volume increased, accidents increased. This trend toward more accidents at the higher volumes was consistent for each type of accident. The same general trend in terms of accidents per million vehicle miles was observed (although it is not shown here). It is also apparent that the range of accident frequency increased considerably with increased traffic volume. Thus, while the total number of accidents in any 1-mile section of

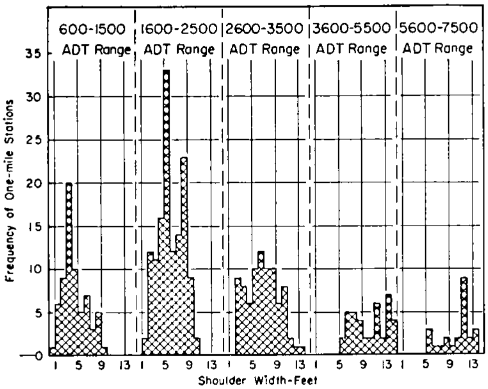

Figure 2. The frequency distribution of shoulder widths as a function of average daily traffic.

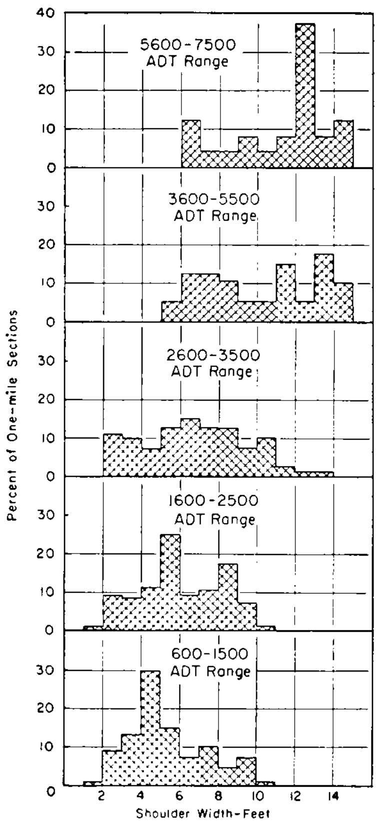

Figure 3. The percentage distribution of shoulder width as a function of the average daily traffic.

the lowest ADT range never exceeded 6 (in the 3-year period involved), as many as 34 accidents occurred in a 1-mile section at the highest ADT. The full impact of volume on accident occurrence may be better appreciated when it is remembered that all 1-mile sections in each group had practically unrestricted sight distance, equal lane width, and were essentially straight and level.

Another property of the accident data appears in Figure 1. A study of the figure reveals the greater prevalence of 1-mile sections having more property damage accidents than injury accidents. The ratio of property damage to injury accidents was approximately 9:4. This relation remained quite constant for all ADT groups. Apparently then, traffic volumes did not affect the type of accident but did contribute heavily to the frequency of accidents of both types.

Shoulder Data

The number of 1-mile sections of each shoulder width is depicted in Figure 2. The frequency of the various shoulder widths is presented for the five ADT groups which increase from left to right in the figure. Examination reveals a marked tendency for shoulder width to increase as the ADT increased. For example, in the lowest ADT range the variation of shoulder width was 1 to 9 feet. The corresponding range for the highest ADT sections was 6 to 14 feet. It would be expected that any operating highway network would have similar distributions since wider shoulders, wider roadways, and other improvements have usually been built into highways as volumes increase.

In addition to depicting the relationship between shoulder width and ADT, Figure 2 illustrates the differences in sample size in the various ADT ranges. It is apparent that most of the 1-mile sections were obtained from low volume highways. Actually less than 20 percent of the sections came from roads which had average daily traffic in excess of 3500 ADT.

The shift in shoulder width as a function of ADT appears in Figure 3 also. This figure shows the percent of 1-mile sections in each ADT range of a given shoulder width. In the lowest ADT range, bottom of Figure 3, about 70 percent of the 1-mile sections have shoulders less than 6 feet in width, whereas 100 percent of the sections in the highest ADT group, top of Figure 3, are 6 feet or wider. This prominent relationship between shoulder width and ADT, together with the similar relationship between accident occurrence and ADT, made it imperative that the appropriate controls be exercised over ADT in order to accurately evaluate the contribution of shoulder width to accident frequency independently of traffic volume.

STATISTICAL TREATMENT

It was the purpose of this investigation to determine how accidents are related to the shoulder widths of the roads on which they occur. In order to properly evaluate the evidence for or against such a relationship, it was necessary to isolate the influence of those roadway features which were not eliminated by the field controls explained above. If such factors—that is, driveways, lane widths, and sight restrictions were not compensated for, it would not have been possible to attribute accident occurrence to shoulder width alone. Only after these extraneous factors were compensated for was it possible to isolate the relationship between shoulder width and accidents.

There were, however, several ways in which this isolation could have been effected. Ideally it might have seemed advantageous to compare the accident occurrences on two roads which were comparable in all respects (e. g., number of commercial driveways) except shoulder width. While this method was theoretically sound, serious objections to it did exist. First, once having established the relationship between shoulder width and accident data, these conclusions would have been applicable only to the particular ADT level encountered under these conditions. In other words, there would have been a marked lack of generality in the results so obtained. Of greater importance, however, was a second practical objection inherent in this procedure. In the field, the likelihood of finding highway sections that were functionally identical in the features to be controlled was infinitesimally slight. What was needed was a technique which would transform the data obtained on dissimilar sections into data which would be expected to result from sections that were comparable in all respects but shoulder width. Fortunately, such a conversion technique was available (called partial correlation). The net effect of this device was to take out those side effects, thus permitting a more perfect understanding of the role of shoulder width in the causation of accidents. The results so obtained correspond to those that would be likely to occur were it actually possible to extract data from roads identical in all features except shoulder width.

FINDINGS

Figures 4 through 6 present theoretical lines which were developed from the accident and shoulder data employed in this study. The development of the linear equations for these lines of accident prediction is presented in detail at the end of Appendix C. These figures were derived from statistical measures which were designed to reveal the effect of one variable (e. g., shoulder width) on a second variable (e. g., traffic accidents) independently of the effects of other variables (e. g., driveways, lane width, and average daily traffic). Lines so developed must be interpreted in light of these controls. That is, lines appearing in Figures 4–6 are useful in that they indicate only the effect of shoulder width on accident frequency when the effects of these other factors (i. e., driveways, lane width, etc.) were eliminated. Saying the same thing differently, theoretical lines were used for the prediction of accident occurrence on highways which were identical in all features save shoulder width.

To facilitate an appraisal and better understanding of the individual findings discussed in detail in this section, it is felt that an explanation of the manner in which these theoretical lines should be interpreted is pertinent. The slope of these theoretical lines is generally indicative of the effect of shoulder width on accident occurrence when such factors as accident and shoulder variability and sample size are held constant. There are three general interpretations which can be placed on the lines as presented in Figures 4–6, inclusive, to wit:

1. Where the theoretical lines are relatively flat, it can be assumed that the effect of shoulder width on accident occurrence is insignificant.
2. Where there is a definite slope downward to the right in the theoretical line of prediction, it is indicated that accident oc-

currence tended to decrease with increases in shoulder width.

a. In two instances the strength of this relationship was such that if there were no real relationship between shoulder width and accident occurrence, these results would have been obtained less than once in 100 times. Such marked instances of the strong influence of shoulder width on accidents were designated in the figures by asterisks.

b. In four instances the slopes of the theoretical lines of accident prediction appeared to show a strong relationship between shoulder width and accidents. Statistically, however, these lines did not reflect a significant relationship between shoulder width and accident occurrence. This lack of significance is possibly due to the limited size of the original sample.

The required sample size necessary to produce a significant relationship between shoulder width and accident occurrence is indicated in the text which describes Figures 4–6. Thus, those theoretical lines which appear to reveal a marked relationship between shoulder width and accidents but are not designated by an asterisk represented the best estimate of the influence of shoulder width on accidents based on data available for this study. It cannot be

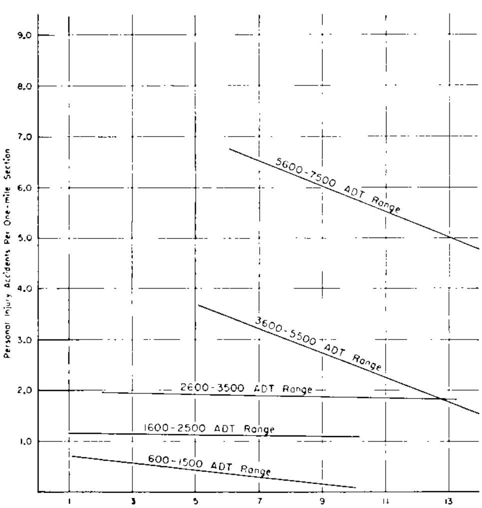

Figure 4. Predicted personal injury accidents from shoulder width and average daily traffic.

said that the marked slopes of these lines revealed the exact effect of shoulder width on accidents but in predicting future accident occurrences even these insignificant findings may have some practical value.

In summary, then, theoretical lines of accident prediction appearing in Figures 4–6 which were nearly horizontal indicated a negligible effect of shoulder width on accident occurrence. Those two lines designated by an asterisk, on the other hand, represented situations wherein could be stated rather conclusively that shoulder width did influence accident occurrence. Those four lines whose slopes markedly differ from zero and which were not designated by an asterisk represented instances where shoulder width probably did exert an influence on accident occurrence (but here the conclusion is considerably less reliable).

Injury Accidents and Shoulder Width

The possible effects of shoulder width on the frequency of personal injury accidents is shown in Figure 4. At the lower ADT's (less than 3600), shoulder widths did not seem to affect the frequency of personal injury accidents whereas there appeared to be an inverse relationship between injury accidents and shoulder width in the two highest ADT ranges. Although the slopes of the latter two theoretical lines appeared to indicate a strong influence of shoulder width on accident occurrence, the latter were not statistically reliable. Had this same measure of the relationship (which is used to develop these theoretical lines as described at the end of Appendix C) been obtained with a larger sample of about 200 one-mile sections, it could have been stated that injury accidents did tend to decrease as shoulders became wider. However, there was no opportunity to test this hypothesis since all available 2-lane tangents at these higher volumes were included in this study and thus an expansion of the sample size in Oregon is impossible at this time. For this reason, accident-shoulder relationships included in Figure 4, though not statistically significant, represent best estimates on the basis of the available data.

The obvious upward displacement of the lines in Figure 4 reflected the increases in accident frequency expected at the higher traffic volumes. Thus, the predicted accident occurrences took into account the inflationary effect of ADT on accidents described previously under "Accident Data."

Property Damage Accidents and Shoulder Width

Figure 5 shows the theoretical frequency of property damage accidents as a function of shoulder width. Again the vertically displaced lines correspond to the differences in average daily traffic. As was the case for personal injury accidents, no reliable relationship between property damage accidents and shoulder width was obtained in the lower ADT ranges (600 through 3500 ADT).

However, in the ADT range 3600 to 5500, a very significant relationship between shoulder width and property damage accidents emerged. In this case, a very reliable decrease in property damage accidents was found when the shoulder width was increased. Thus, on 1-mile sections which were similar in all respects except shoulder width, it would be predicted that about 11 accidents would occur on any 1-mile section having shoulders 5 feet wide as compared with about 3 accidents on any section having shoulders 14 feet wide (over a 3-year period). Apparently then, shoulder width, or some unknown factor closely related to it, was definitely responsible for reduction in property damage accidents. The strength of this relationship was indicated by the fact that if no relationship existed between shoulder width and property damage accidents in this ADT range, the statistical results obtained would occur less than once in 100 times. In this light, it was reasonable to assume that wider shoulders did reduce property damage accidents on 2-lane rural tangents in this ADT range.

Although the accident-shoulder relationship in the 5600 to 7500 ADT range appeared to parallel that of the 3600 to 5500 ADT range, the strength of the relationship between shoulder width and accident data was not as great in the higher ADT range. An explanation of the statistical insignificance of the apparent reduction in accident frequency with increases in shoulder width was sought. Subsequent analyses which are described in detail in Appendix D provided information which led to the assumption that a speed factor may have tended to work against the advantages of wider shoulders as a factor in the reduction of property damage accidents. Because the theo-

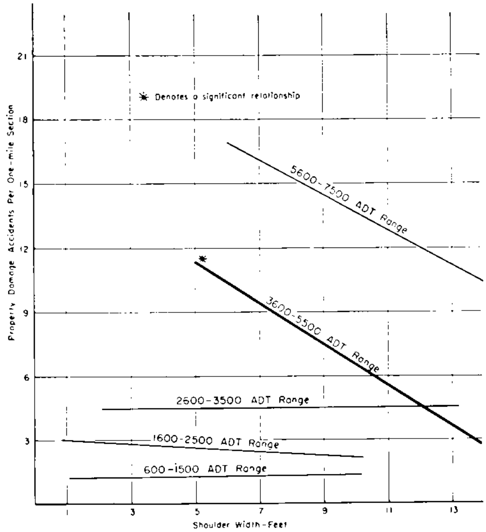

Figure 5. Predicted property damage accidents from shoulder width and average daily traffic.

retical line for the 5600 to 7500 ADT range does not take into account the differential effect of vehicular speed at the various shoulder widths, it is difficult to assess exactly the influence of shoulder width on accident occurrence in this ADT range.

Had similar results been obtained with a sample size of approximately 180, the effects of shoulder widths on accident data would be clear-cut, the effects of vehicular speed notwithstanding. Thus, while the theoretical line for property damage accidents in this highest ADT range is not statistically significant, for any interpretation of this predicted measure one should bear in mind the effects of a speed factor which tended to operate in a direction opposite to that of shoulder width itself.

Total Accidents and Shoulder Width

The relationship between total accidents and shoulder width is graphically presented in Figure 6. As would be expected on the basis of the results found for both personal injury and property damage accident relationships with shoulder width, total accidents were unaffected by shoulder width in the lower ADT ranges (below 3600).

In the 3600 to 5500 ADT range, total accidents were significantly reduced by an increase in shoulder width. This result mirrored that found for property damage in this ADT range.

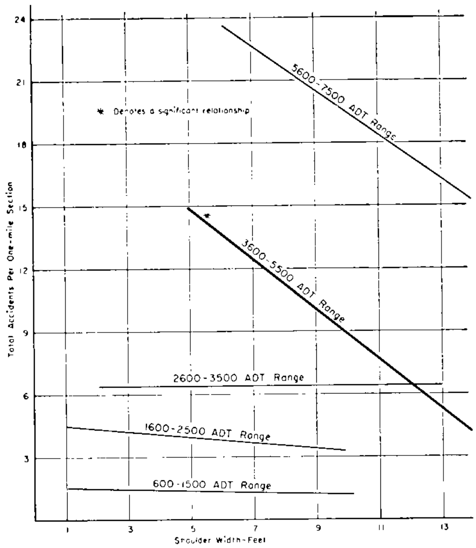

Figure 6. Predicted total accidents from shoulder width and average daily traffic.

This result was not unlikely, in view of the fact that there were nearly twice as many property damage accidents as personal injury accidents. In this case it is predicted that about 15 accidents would occur on 1-mile sections having 5-foot shoulders and fewer than five accidents on mile sections having 14-foot shoulders (over a 3-year period). Again, if there were no true relationship between total accidents and shoulder width, the probability of obtaining results of this type is less than one in 100.

In the 5600 to 7500 ADT range, total accidents were not affected in the same way by shoulder width as in the next lower ADT range (3600 to 5500 ADT). It appears, on the basis of the theoretical line produced in Figure 6, that increases in shoulder width tended to decrease total accidents, although this tendency was not as marked, and the basis for this insignificant relationship was again sought in terms of the differential effects of vehicular speeds on this highest ADT range. Because the larger proportion of total accidents was comprised of property damage accidents, it was reasonable to assume that this speed factor which tended to reduce the safety benefits of wider shoulders in terms of property damage accidents was merely reflected in the analysis of the total accidents presented in Figure 6. It would be expected that had the differential effects of vehicle speeds and the various shoulder widths been removed prior to a graphic presentation of the accident-shoulder width relationship, the influence of wider shoulders in the reduction of total accidents would be more apparent and possibly statistically significant.

DISCUSSION OF RESULTS

Probably the most important finding in this investigation was that accident frequency was not affected by shoulder width for the lower ADT highways (ADT less than 3600). Highways in this volume range constituted the bulk of the rural, 2-lane Oregon primary highways. Even in terms of total vehicle miles, these roads were the most used 2-lane tangents in Oregon. The finding that shoulder width did not affect accident occurrence was supported by the fact that accident occurrence did not seem to be related to any other roadway feature controlled in this study (e. g., commercial and residential driveways, lane width, curves, terrain, or sight restrictions). It appeared then that accidents occurring in this ADT range were truly accidents in the sense that they were not causally related to any other single roadside feature, or to any combination of those factors considered in this study. When it is remembered that these sections were of universally low volume, straight and level, had practically no sight restrictions, and all had at least 10-foot lanes, it seemed reasonable to attribute the accidents occurring on these sections to driver characteristics and chance occurrences rather than to any construction feature of the roadway itself. It is also conceivable that speed could be entering into these results but we have no factual data to support this supposition.

The second important finding, this time positive in nature, was a tendency toward a reduction in accidents as shoulder width was increased in the higher ADT ranges. This tendency was statistically reliable for total accidents and property damage accidents in the 3600 to 5500 ADT range. Because the total accident trend reflected the property damage trend, only the latter need be considered here (i. e., the total accidents were influenced in the direction of property damage accidents because there were nearly twice as many property damage accidents as personal injury accidents). This observed inverse relationship between shoulder width and accident frequency concurs with the implicit assumptions of highway designers who have felt that something must be done to alleviate congestion on higher ADT 2-lane roadways. In practice, one of the things that has been done was a widening of the shoulders. On the basis of the results of this study, it appears reasonable to suspect that these shoulder improvements actually were helpful in this volume range on 2-lane rural tangents.

Critical analysis of the accident data did not reveal which of the attendant advantages of wider shoulders was responsible for this decrease in accident frequency for sections with wide shoulders. Thus, it was not known why sections with wider shoulders were safer —such as the greater clearance between meeting vehicles as contrasted with narrow shoulders, greater off-the-road parking space, or greater emergency maneuverability. In any event, it was safe to assume that sections of 2-lane tangents which had wide gravel shoulders were safer than comparable sections with narrow shoulders. This safety factor was either due to increased shoulder width or to a factor closely related to wide shoulders and appeared independently of the effects of driveways, lane widths, sight restrictions, and traffic volume variations in this 3600 to 5500 ADT range.

The insignificant, though apparent, relationship between personal injury accidents and shoulder width was due to the greater variability in personal injury accidents (i. e., greater tendency for personal injury accidents to vary in number from one section to another). It is conceivable that this lack of relationship or increased variability actually reflected the introduction of a second factor which tended to increase injury accidents on the sections with wider shoulders and thus ran counter to the increased safety benefits provided by tangents with wider shoulders. This second factor, as yet unidentified, could be the same one that is responsible for the production of the positive relationship between injury accidents and shoulder width found by Belmont in California.[3] Whatever this second factor may have been, its effect might have been accentuated when paved shoulders were considered, as was the case in the California study. However, until evidence of a more concrete nature is available, attempts to propose a second factor which would tend to resolve the differences between the Oregon and California findings must remain pure speculation. In view of the findings of this study, it could only be stated that personal injury accidents appeared to decrease as shoulder width was increased but that this apparent relationship did not achieve statistical confirmation. It is conceivable that injury accidents were actually reduced by the wider shoulders, but one should be cautious in assuming this in view of the limitations in sample size considered here.

The insignificance of the apparent relationship between shoulder width and all types of accidents in the highest ADT range (5600 to 7500) stemmed from an increase in the variability of the accident data in this ADT range. This time, however, there was evidence of a more concrete nature that a second factor was at least partially responsible for this greater variability, and hence, the lack of a reliable inverse relationship between accidents and shoulder width. Fortunately, speed checks were available for many of the sections in the 3600 to 5500 ADT range as well as in the 5600 to 7500 ADT range. Analysis of the speed data as a function of shoulder width indicated that no significant relationship existed between shoulder width and speed in the 3600 to 5500 ADT range whereas a highly positive relationship emerged between speed and shoulder width in the 5600 to 7500 ADT range. These are illustrated in Figure 7. In other words, vehicles actually moved faster on 1-mile sections having wide shoulders than on 1-mile sections with narrow shoulders in this higher ADT range. It was conceivable that this positive relationship between shoulder width and vehicle speed operated to reduce the safety value of wide shoulders that would ordinarily be enjoyed. Apparently then, the detracting influence of increased speed on the benefits of the wider shoulders was partially responsible for the insignificance of the tendency for a reduction in accident frequency on wider shoulders.

Other factors also may be contributing to this relationship. It was also possible, however, that fewer accidents were actually associated with wide shoulders, and that this relationship did not become prominent in this investigation

[3] "As shoulder width increases, drivers may gain an unjustified feeling of security. Speed may increase, with an attendant increase in accident rates" (number of accidents).

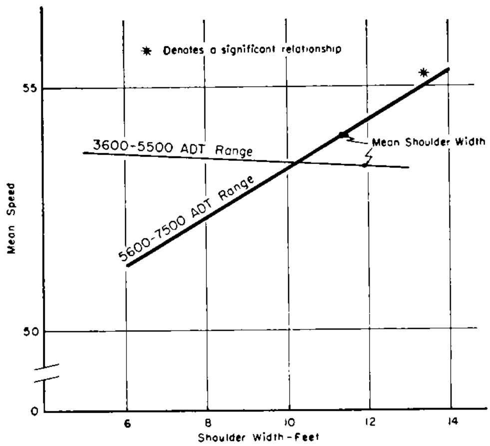

Figure 7. Vehicle speed versus shoulder width.

because of the natural restrictions of the sample size at this ADT range. If the same numerical index of relationship between shoulder width and total accidents was obtained for a sample of 40 cases instead of the 24 involved here, it would then be statistically reliable. Again, it should be recalled that the data analyzed in this study exhausted all available sources in Oregon which satisfied the other criteria such as two lanes, 30 percent or less sight restriction, and essentially straight and level roadways in the time period covered.

In summary, it appeared that the contribution of shoulder width to accident occurrence taken by itself was generally slight on the lower volume roads (ADT less than 3600). On higher volume roads (3600 to 7500 ADT), wide shoulders tended to reduce accidents, especially property damage and total accidents. However, when there was a significant increase in vehicle speed with wide shoulders as was found in the 5600 to 7500 ADT range, this tendency for a reduction in accidents with wide shoulders fell short of statistical significance. In line with the findings of Belmont's California study (*4*), there appears the possibility that personal injury accidents were affected by shoulder width in a somewhat different way than was the case for property damage accidents. At the time of this writing, the cause of this discrepancy between the two types of accidents, namely, personal injury and property damage accidents, is unknown—unless paved shoulders account for it.

SUMMARY OF FINDINGS

1. There was no relation between accident frequency and shoulder width on 2-lane tangents of less than 3600 ADT.
2. In the two highest ADT ranges (3600 to 5500—5600 to 7500), the frequency of all types of accidents appeared to decrease as shoulder widths increased.
3. Statistically, the only reliable trends were that total accidents and property damage accidents decreased as shoulder widths increased in the 3600 to 5500 ADT range.

CONCLUSIONS

The insignificant effect of shoulder width at the lower volumes is not startling. In fact, accident occurrence was unrelated to any single roadway feature at these low traffic levels. However, in view of the significant relationship of total accidents and property damage accidents to shoulder width in the 3600 to 5500 ADT range, a similar finding might have been expected in the next higher volume group (5600 through 7500 ADT). That this expectation was not realized may be attributable in part to either the limited size of the sample or the strong tendency for speed to increase with a widening of the shoulders in the highest volume group, whereas no such relationships held in the 3600 to 5500 ADT group. Actually, motorists successfully endeavored to maintain speeds in the 5600 to 7500 ADT range at least as high as those recorded in the next lower volume range and thereby may have nullified the beneficial effects of wide shoulders.

The insignificance of the relationship between shoulder width and injury-type accidents implied that wide shoulders were not as effective in deterring personal injury accidents as they appeared to be in reducing property damage accidents. This differential effect of shoulder width on accident type was not in the direction of Belmont's findings (*4*), which indicated that injury accidents increased with shoulder width. No such marked hazardous effect of wide shoulders on personal injury accidents was encountered in this study. This discrepancy may be sought in terms of the differences in shoulder type (gravel vs. paved shoulders) and in the generally lower volume highways studied in Oregon.

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APPENDICES

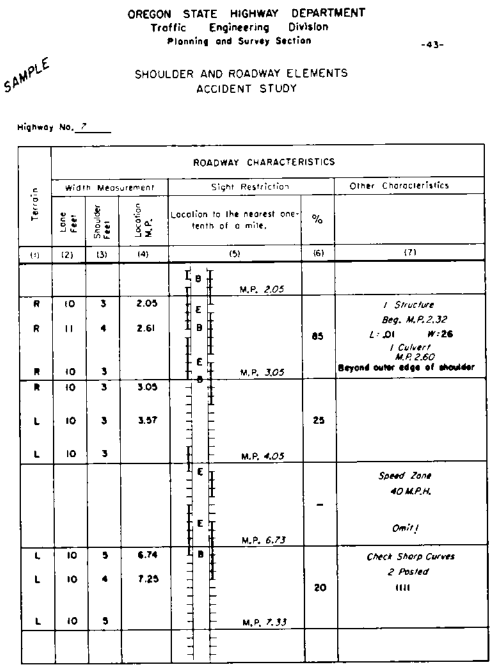
A. SOURCE OF RAW DATA

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 will follow directly.

Field Data

The observer's 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 odometers which permitted identification of the exact location at which measurements and other observations were made. The odometers were readable to one hundredths of a mile. Previously, field sheets had been prepared which provided ample space for the convenient recording of all data. Figure 8 shows a sample field sheet. The material in slant print was placed on the field sheet by the Accident Analysis Section prior to the observer's trip to the field. It included a designation of the observer's route by consecutive 1-mile sections (see Column 5 of field sheet). In addition, the number and location of structures, the location of known speed zones and reminders to check sharp curves were written in Column 7 under the heading of "Other Characteristics." 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, designated in slant print in Column 5, the field observer would record the terrain description. The abbreviations "L" for level, "R" for rolling, and "M" for mountainous were employed throughout and appear in bold print in Column 1. 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, shown in bold print in Columns 2 and 3, respectively. 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 section were also recorded and appear in bold print in 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 particular 1-mile



SAMPLE

OREGON STATE HIGHWAY DEPARTMENT
Traffic Engineering Division
Planning and Survey Section

-43-

SHOULDER AND ROADWAY ELEMENTS
ACCIDENT STUDY

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	10	3	2.05	E		1 Structure
R	11	4	2.61	B	85	Beg. M.P. 2.32 L: .01 W: 26 1 Culvert M.P. 2.60
R	10	3		E M.P. 3.05		Beyond outer edge of shoulder
R	10	3	3.05	B		
L	10	3	3.57		25	
L	10	3		M.P. 4.05		
				E		Speed Zone 40 M.P.H.
					–	
				E M.P. 6.73		Omit!
L	10	5	6.74	B		Check Sharp Curves
L	10	4	7.25		20	2 Posted IIII
L	10	5		M.P. 7.33		

Figure 8. Sample field sheet.

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 as the last sectional entries 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 of the field sheets were utilized in recording sight distance restrictions. As the observer proceeded through a mile section, special notations were made concerning the location of the beginning of unrestricted sight (1500 feet of pavement visible) and the ending of unrestricted sight. At that point which appeared to the observer to be the beginning of insufficient sight distance, a "B" was recorded (correct to the nearest 0.1 of a mile) in Column 5 of the field sheet. This denoted not only the aforementioned beginning point, but also designated the end point of pavement visibility for vehicles traveling in the opposite direction. The observer would then note the point ahead of him where the pavement disappeared either vertically or horizontally and, upon reaching that point, its location was also placed at the appropriate point on the field sheet. The letter "E" was used to designate this place of ended sight clearance for vehicles traveling in the direction of the observer (indicated by an arrow at the top of Column 5) and ended sight restriction for those vehicles traveling in the opposite direction.

Upon the field observer's return to the office, he would blank out (indicated by the vertical lines in Column 5) any 0.1 of a mile sections in either direction of travel that did not have the required 1500 feet (0.3 of a mile) sight clearance. In this manner, it was possible to determine in steps of 5 percent the amount of sight restriction present for each 1-mile section, and these determinations appear in Column 6 in bold print.

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 of the field sheet (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 and appear on the field sheet in bold print. In a similar way, the observer's tabulation of the number of sharp curves was recorded and appears in bold print also. In those cases where a culvert was indicated, the observer 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 (see Table 1). These field data appear 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 and a description follows below.

Office Data

An estimate of the ADT for each 1-mile section was developed from the data of Traffic Volume Tables for 1953 (*5*). 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 on which shoulder data were available.

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. However, only the latter were considered in this investigation. The completed code sheet provided the following information for each 1-mile section which satisfactorily met the prescribed criteria for the inclusion in this study: terrain, lane width,

TABLE 1
Oregon State Highway Department
Traffic Engineering Division
Shoulder Study

AMPLE

Hwy No.	Section No.	Mile Post		Sight Restriction %	Terrain	Curves	Drvwy.		A.D.T. in Hundreds	Shoulder	Lane	Accidents																	
												1952						1953						1954					
												Non inters.			Inters.			Non inters.			Inters.			Non inters.			Inters.		
		From	To				Commercial	Residential				F	NF	PD	F	NF	Pd	F	NF	PD	F	NF	PD	F	NF	PD	F	NF	PD
07	01	00205	00305	**85**	**1**	0	00	01	23	**03**	**10**	0	1	05	0	0	00	0	2	00	0	0	02	0	0	05	0	0	01
07	02	00305	00405	**25**	**0**	0	01	02	23	**03**	**10**	0	0	00	0	0	00	0	1	03	0	0	00	0	0	06	0	0	00
07	03	00673	00773	**20**	**0**	**4**	00	00	26	**05**	**10**	0	3	04	0	1	02	0	2	04	0	1	03	0	2	03	0	1	03

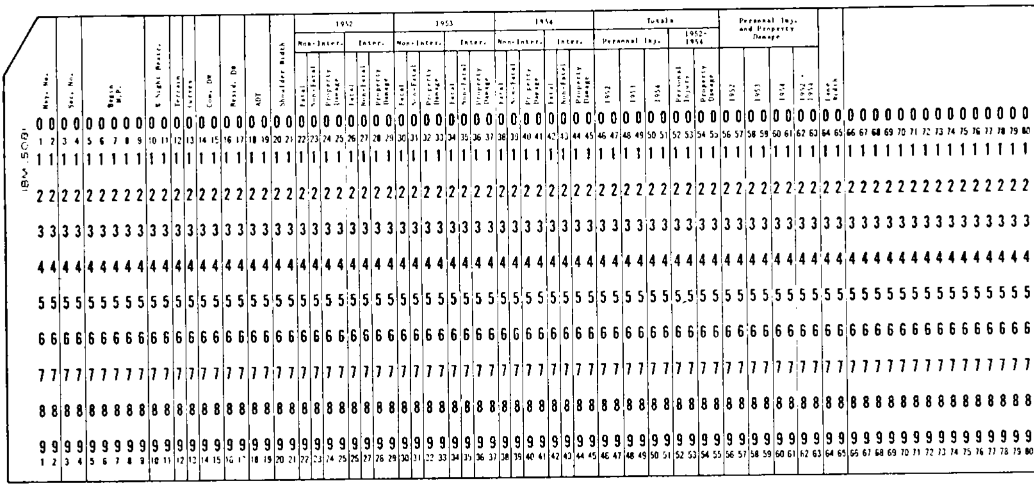


Figure 9. IBM card layout-shoulder study.

shoulder width, sight restriction, ADT, and personal injury, property damage and total accidents for each year from 1952 to 1954.

B. IBM PROCEDURE

The data on the completed code sheets were then key punched into IBM cards. From this point on in the procedure, the code sheets were no longer directly utilized but were retained as a duplicate record. The first stage in the IBM computation involved developing the totals of each accident variety (person injury, property damage, and total accidents) for the 3-year period 1952–1954. The effect of this procedure was to produce a total personal injury, a total property damage, and a total combination accident based on a 3-year period. The IBM calculating punch type 602-A was employed in this summation in order that each total would be punched on the same card on which the factors appeared.

Using the same piece of equipment, the sums of squares and the sums of cross products among all the factors under consideration were developed. The IBM accounting machine was employed to print the totals of each factor. By means of these last two operations, and with a knowledge of the sample size in each ADT range, all the information necessary for the computation of correlation coefficients was available. Prior to these operations, however, the cards were sorted on the basis of ADT and grouped in five ranges as follows: 600 through 1500, 1600 through 2500, 2600 through 3500, 3600 through 5500, and 5600 through 7500.

Figure 9 shows a sample IBM card. The type of information appearing there from left to right and the column so used, shown in parenthesis, are as follows: Highway Number (1, 2); Section Number (3, 4); Beginning M.P. (5 through 9); Sight Restriction (10, 11); Terrain (12); Curves (13); Commercial Driveways (14, 15); Residential Driveways (16, 17); ADT (18, 19); Shoulder Width (20, 21); Accidents (22 through 45); Calculated Accidents Total (46 through 63); and Lane Width (64, 65).

With the exception of the lane-width measurements, the data on the IBM card appear in the order shown on the code sheet described above.

C. PARTIAL CORRELATION TECHNIQUE

The first step in the development of the higher order partial correlation was the derivation of the zero order, or Pearsonian, correlation coefficients. The zero order correlation coefficients were derived from Equation 1 shown below

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

where: N = the number of 1-mile sections within the ADT range under investigation,

ΣX = the sum of the shoulder widths in feet for all 1-mile sections in the sample,

ΣY = the sum of the accident frequencies for all 1-mile sections in the sample,

ΣY^2 = the sum of the number of accidents squared for all the 1-mile sections in the sample,

ΣX^2 = the sum of the width of shoulders squared for all the 1-mile sections in the sample,

ΣXY = the sum of the products resulting from the multiplication of the shoulder width and the accident frequency for each mile section in the sample.

As shown in Equation 1, the two sums of squares, the sum of cross products, the two individual sums, and the sample size are the only data required for this calculation.

The results of the IBM computations provided this information. Its insertion in this formula and the subsequent calculation was accomplished with a desk calculator. The zero order correlation coefficients between sight restriction and accident type for each ADT range appear in Table 2. These relationships were of interest as a check on the advisability of setting a critical sight restriction of 30 percent above which no shoulder sections would be included. The correlation coefficients in Table 2 corroborated the assumption that 30 percent sight restriction would not be appreciably different from zero sight restriction with regard to its effect on accident data for straight and level 2-lane rural tangents. In light of these results, it was considered reasonable to rely on the field controls and thus omit the extra encumbrance of controlling sight restriction again by the partial correlation technique. Subsequent analyses then will deal with the removal of the effects of residential driveways, commercial driveways, lane width, in all ADT groups, and the additional control of ADT variations within the two highest ADT ranges.

Zero order correlation coefficients appear in Table 3. In this table the various inter-correlations and their degrees of significance are presented. The frequent significant effects of such factors as commercial driveways, residential driveways, and lane width on accidents point up the necessity of controlling these factors when the relationship between shoulder width and accidents was considered independently. For example, a high and positive relationship between lane width and shoulder width made it imperative that lane width be controlled statistically as well as in the field. Otherwise, it would have been impossible to state whether fewer accidents were due to the wider shoulders or to wider lanes. In similar ways, the necessity of controlling driveways was rationalized.

In recognition of the possibility that other

TABLE 2

THE ZERO ORDER CORRELATION COEFFICIENTS FOR THE "ACCIDENT-SIGHT RESTRICTION" RELATIONSHIPS

ADT Range	Personal Injury	Property Damage	Total Accidents
600–1500	0.056	0.023	0.040
1600–2500	−0.002	0.027	0.020
2600–3500	0.063	0.021	0.041
3600–5500	0.067	0.034	0.057
5600–7500	0.050	−0.013	0.005

TABLE 3

ZERO ORDER PARTIAL CORRELATION COEFFICIENTS FOR EACH ADT LEVEL

	ADT Range	Personal Injury	Property Damage	Total Accidents	Commercial Driveways	Residential Driveways	Lane Width
Shoulder Width	600–1500	−0.224	−0.009	−0.102	−0.021	0.035	0.690†
	1600–2500	−0.031	−0.102	−0.091	−0.028	−0.262†	0.513†
	2600–3500	−0.132	−0.121	−0.147	−0.110	−0.137	0.370†
	3600–5500	−0.349*	−0.623†	−0.581†	−0.433†	−0.558†	0.463†
	5600–7500	−0.224	−0.588†	−0.560†	−0.177	−0.550†	0.476*
Lane Width	600–1500	−0.220	−0.056	−0.136	−0.040	−0.028	
	1600–2500	−0.048	−0.039	−0.051	−0.158	−0.134	
	2600–3500	−0.435†	−0.374†	−0.464†	−0.332†	−0.490†	
	3600–5500	−0.188	−0.460†	−0.405*	−0.370*	−0.396*	
	5600–7500	−0.347	−0.387	−0.432*	−0.293	0.103	
Residential Driveways	600–1500	0.226	0.427†	0.414†	0.184		
	1600–2500	−0.002	0.125	0.093	0.184*		
	2600–3500	0.538†	0.556†	0.649†	0.575†		
	3600–5500	0.300	0.417†	0.412†	0.549†		
	5600–7500	0.192	0.467*	0.449*	0.479*		
Commercial Driveways	600–1500	0.076	0.048	0.068			
	1600–2500	0.321†	0.229†	0.315†			
	2600–3500	0.444†	0.520†	0.585†			
	3600–5500	0.536†	0.618†	0.643†			
	5600–7500	0.687†	0.397	0.548†			
Total Accidents	600–1500	0.742†	0.924†				
	1600–2500	0.710†	0.909†				
	2600–3500	0.662†	0.935†				
	3600–5500	0.830†	0.964†				
	5600–7500	0.656†	0.956†				
Property Damage	600–1500	0.421†					
	1600–2500	0.350†					
	2600–3500	0.357†					
	3600–5500	0.655†					
	5600–7500	0.406*					

* Indicates that were it possible to obtain 100 samples of similar size from the same population of shoulder width, accidents, lane widths, etc., relationships different from zero would be expected to occur 95 times in those 100 samples.

† Indicates that were it possible to obtain 100 samples of similar size from the same population of shoulder width, accidents, lane widths, etc., relationships different from zero would be expected to occur 99 times in those 100 samples.

factors may have overshadowed or distorted the real relationship between accident occurrence and shoulder width, the effects of commercial driveways, residential driveways, lane width, and ADT variations were sequentially controlled in the following way. The effect of this approach was to hold constant a third factor during the examination of the relationship between two other factors. (For example, the relation between shoulder width and accidents with the effect of commercial driveways held constant.) The index which reveals this controlled relationship is referred to as partial correlation and is designated as $r_{12.3}$. Its formula appears in Equation 2 below (*6*):

$$r_{12.3} = \frac{r_{12} - r_{13}r_{23}}{\sqrt{1 - r_{13}^2}\sqrt{1 - r_{23}^2}} \qquad (2)$$

All of the factors required in this formula are available in Table 3. For example, in order to understand the relationship between personal injury accidents (factor 1) and shoulder width (factor 2) with the effect of commercial driveways (factor 3) removed, the following zero order correlation coefficients would be required: shoulder width and personal injury (r_{12} = −0.224), personal injury and commercial driveways (r_{13} = +0.687), and shoulder width and commercial driveways (r_{23} = −0.177). Inserting these values in Equation 2, the relationship between shoulder width and personal injury is indicated by a first order partial correlation coefficient of ($r_{12.3}$ = −0.143) which appears in the bottom of Column 1 of Table 4*A*. In a similar way, all of the other first order partial correlation coefficients between shoulder width and accident occurrence were derived and appear in Table 4*A*.

TABLE 4

SUCCESSIVE PARTIAL CORRELATION COEFFICIENTS AFTER THE REMOVAL OF COMMERCIAL DRIVEWAYS (4*A*), RESIDENTIAL DRIVEWAYS (4*B*), LANE WIDTH (4*C*), AND ADT (4*D*)

ADT Range	Personal Injury (1)	Property Damage (2)	Total Accidents (3)
4*A*—Commercial Driveways Controlled			
600–1500	−0.222	−0.008	−0.101
1600–2500	−0.023	−0.099	−0.086
2600–3500	−0.093	−0.075	−0.102
3600–5500	−0.154	−0.500†	−0.439*
5600–7500	−0.143	−0.569*	−0.558*
4*B*—Commercial and Residential Driveways Controlled			
600–1500	−0.237	−0.026	−0.127
1600–2500	−0.042	−0.080	−0.079
2600–3500	−0.063	−0.045	−0.068
3600–5500	−0.166	−0.500*	−0.441
5600–7500	−0.313	−0.489	−0.522
4*C*—Driveways and Lane Width Controlled			
600–1500	−0.218	0.011	−0.048
1600–2500	−0.016	−0.097	−0.094
2600–3500	−0.016	−0.001	0.007
3600–5500	−0.179	−0.459	−0.411
5600–7500	−0.297	−0.251	−0.489
4*D*—ADT, Driveways, and Lane Width Controlled			
3600–5500	−0.325	−0.625†	−0.602†
5600–7500	−0.229	−0.288	−0.478

* Indicates that were it possible to obtain 100 samples of similar size from the same population of shoulder width, accidents, lane widths, etc., relationships different from zero would be expected to occur 95 times in those 100 samples.

† Indicates that were it possible to obtain 100 samples of similar size from the same population of shoulder width, accidents, lane widths, etc., relationships different from zero would be expected to occur 99 times in those 100 samples.

An expansion of the partial correlation technique outlined above allows the examination of the relationship between any two variables with the effects of any number of other variables held constant. The general form of this formula appears in Equation 3 below (*6*):

$$r_{12.34\cdots n} = \frac{r_{12.34\cdots(n-1)} - [r_{1n.34\cdots(n-1)}][r_{2n.34\cdots(n-1)}]}{\sqrt{1 - r^2_{1n.34\cdots(n-1)}}\sqrt{1 - r^2_{2n.34\cdots(n-1)}}} \qquad (3)$$

Thus, to obtain the relationship between shoulder width and accident occurrence with the effects of two other variables controlled, for example commercial and residential driveways, Equation 3 becomes the following:

$$r_{12.34} = \frac{r_{12.3} - r_{14.3}r_{24.3}}{\sqrt{1 - r^2_{14.3}}\sqrt{1 - r^2_{24.3}}} \qquad (4)$$

Here accidents were designated by 1, shoulders by 2, commercial driveways by 3, and residential driveways by 4. Examination of this equation revealed that additional first order partial correlation coefficients were required beyond those shown in Table 4*A*. These others were developed from Table 3 in the same way as those appearing in Table 4*A*. By substituting the appropriate values into the formula, the relationship between shoulder width and accident data with the effects of commercial and residential driveways, both controlled, were derived. These relationships appear in Table 4*B*

A continuation of the above procedure permitted the further isolation of the effects of shoulder width on accident occurrence when the effects of commercial driveways, residential driveways, and lane width were simultaneously controlled. The formula for the third order partial correlation coefficient was as follows:

$$r_{12.345} = \frac{r_{12.34} - r_{15.34}r_{25.34}}{\sqrt{1 - r^2_{15.34}}\sqrt{1 - r^2_{25.34}}} \qquad (5)$$

Here 1 through 4 designated the same factors as in Equation 4 above and factor 5 represented lane width. Substituting the required values, the third order partial correlation coefficients were derived and appear in Table 4*C*.

It was considered worthwhile to investigate the relationship between shoulder width and accident occurrence in the two highest volume ranges when the variations in ADT within these ranges were held constant. This statistical control of volume appeared to be necessary since these two volume ranges contained an ADT range of 2000 as compared with an ADT range of 1000 in the three lower volume groups. Table 4*D* presents the results of these analyses in which the effect of ADT was "partialled" out within each of the two highest ADT ranges.

The level of significance of the results presented in the tables above took into account the sample size and the number of variables involved in the partial correlation. A table of the significant values produced by H. A. Wallace and G. W. Snedecor was used for these interpretations (7). Theoretical lines of Figure 4 through 6 in the main part of this paper were based on the partial correlation coefficients which appear in Table 4 (*C* and *D*). The curves for the theoretical lines for the three lower ADT groups were derived from the indices which appear in Table 4*C*. The regression lines for the two higher volume groups were based on the fourth order partial correlation coefficients which appear in Table 4*D*.

The regression lines were developed in the following way. The general form of any linear equation is shown in Equation 6 below.

$$Y = bX + a \tag{6}$$

where: Y = number of accidents predicted on the basis of X
X = shoulder width in feet
b = the slope of the line, and
a = the y intercept.

The appropriate a and b values in Equation 6 are derived from a partial regression equation which is expressed below in Equation 7.

$$Y = r_{yx\cdot tuvw}\left(\frac{\sigma_y}{\sigma_x}\right)(X - M_x) + M_y \tag{7}$$

where: $r_{yx\cdot tuvw}$ = the partial correlation coefficient representing the degree of relationship between accidents, y, and shoulder width, x, with variables t, u, v, w, which represent commercial driveways, residential driveways, lane width and ADT held constant
σ_y = a measure of accident variability in terms of the standard deviation
σ_x = a similar measure of shoulder variability
X = a particular shoulder width value expressed to the nearest foot
M_x = the arithmetical average of all the shoulder widths
M_y = the arithmetical average of all accidents.

When the factor $r_{yx\cdot tuvw}$ times (σ_y/σ_x) is multiplied through by $(X - M_x)$, Equation 7 becomes

$$Y = r_{yx\cdot tuvw}\left(\frac{\sigma_y}{\sigma_x}\right)X - r_{yx\cdot tuvw}\left(\frac{\sigma_y}{\sigma_x}\right)M_x + M_y \tag{8}$$

Comparison of Equations 6 and 8 reveals the first term on the right of both equations is a constant (b in Equation 6 and $r_{yx\cdot tuvw}$ times (σ_y/σ_x) in 8) times the X value. The remaining terms in Equation 8 ($r_{yx\cdot tuvw}$ $(\sigma_y/\sigma_x)M_x$ and M_y) may be combined to form a constant which is the counterpart of a in Equation 6. A detailed sample of the application of the equation follows directly.

Given: $r_{yx\cdot tuvw} = -0.602$

where: Y = frequency of total accidents
X = frequency of shoulder width in feet
$r_{yx\cdot tuvw}$ = a measure of the relationship between total accidents, y, and shoulder width, x, when the effects of commercial driveways, t, residential driveways, u, lane widths, v, and ADT, w, are controlled.

When a value of −0.602 was calculated as described earlier and is found in the righthand column of Table 4*D* in the first row:
$\sigma_y = 2.923$
$\sigma_x = 5.923$ where σ_x and σ_y are derived from the raw data as follows:

$$\sigma_x = \frac{\sqrt{N\Sigma X^2 - (\Sigma X)^2}}{N} \tag{9}$$

$$\sigma_y = \frac{\sqrt{N\Sigma Y^2 - (\Sigma Y)^2}}{N} \tag{10}$$

where: X, Y, X^2, Y^2 and N have the same meaning as that described after Equation 1 given earlier in Appendix C
M_x = 9.795 feet, which is the average shoulder width in the 3600 to 5500 ADT range
M_y = 9.231 accidents over a 3-year period, in the above ADT range.

Substituting these values in Equation 8, the regression equation becomes

$$Y = -0.602\left(\frac{5.923}{2.923}\right)X + 9.231 - 0.602\left(\frac{5.923}{2.923}\right)9.795 \tag{11}$$

which simplified reduces to

$$Y = -1.22X + 21.181 \tag{12}$$

When the various X, that is, shoulder width values in Equation 12, are inserted, the pre-

TABLE 5

ZERO ORDER CORRELATION COEFFICIENTS OF SPEED WITH ADT, COMMERCIAL DRIVEWAYS, AND SHOULDER WIDTH

ADT Range	Speed and ADT (1)	Speed and Commercial Driveways (2)	Speed and Shoulder Width (3)	Shoulders and Commercial DWS (4)	ADT and Commercial DWS (5)	Shoulders and ADT (6)
3600–5500	−0.370	−0.583	0.530	−0.801	0.308	−0.612
5600–7500	0.228	−0.499	0.654	−0.060	0.100	0.277

dicted accident values appearing in Figure 6 result. For example, when the shoulder width is 5 feet, the expected frequency of accidents is 21.181 (found at the right on Equation 12) minus the product of 1.22 × 5 (shoulder width) or a predicted accident frequency of 15.08. With shoulder widths of 14 feet, the predicted number of accidents would be obtained by subtracting from 21.181 the product of 1.22 × 14 or 4.10 accidents over a 3-year period.

All the theoretical lines presented in Figures 4 through 6 were developed in an identical way to that described in the above example. The theoretical lines in Figure 7 which depict vehicular speed as a function of shoulder width employed the same technique with the exception that vehicular speed instead of accident frequency was predicted in this instance.

D. ANALYSIS OF SPEED DATA

In an attempt to explain the lack of significance between shoulder width and accident occurrence, a second factor was sought which might have introduced the greater variability observed in the accident data in the highest ADT range. Fortunately, speed checks were available for a number of the 1-mile sections in the 3600 to 5500 ADT range and in the 5600 to 7500 ADT range. These data appear in Table 5.

Of the 39 sections in the 3600 to 5500 ADT range, speed checks were available for 17 sections. Speed checks were available for 22 of the 24 one-mile sections in the highest volume range (5600 to 7500 ADT). The mean speed in the highest volume range was 54.0 miles per hour as compared to 53.36 miles per hour in the next lower ADT range. This slight difference was insignificant. It might be important to note, however, that motorists did attempt to maintain the same speed in the highest volume range as in the next lower volume range. In view of the fact that the mean volume (6887) is 55 percent higher than the mean volume in the lower ADT range (4431), it appeared then that this rather considerable increment in ADT did not cause the driver to reduce the speed of his vehicle.

In Table 5*A* there appears the zero order correlations between speed and volume, shoulder width, and commercial driveways. By means of these data and that of Table 5*B*, the correlation coefficient between speed and shoulder width was calculated with the effects of commercial driveways and ADT held constant. These correlations were −0.039 in the 3600 to 5500 ADT range and +0.676 in the 5600 to 7500 ADT range. The former figure of course is insignificant, whereas, the latter is reliable at the 1 percent level of confidence. In summary, then, it appears that drivers attempt to maintain the same speed on highways of high volume as they do on highways of intermediate volume (3600 to 5500 ADT) and on the former roadways they tend to travel faster when the shoulders are wider. No such relationship between shoulder width and vehicular speed occurred in the intermediate ADT range (3600–5500). It appeared as a reasonable possibility that these increased speeds on the sections with wider shoulders tended to work against the safety features provided by these wider shoulders. The joint effect of increased speeds and increased safety benefits from wide shoulders tended to increase the variability in the accident data recorded on these sections, thereby reducing the strength of the relationship between shoulder width and accident occurrence. Figure 7 shows vehicle speed as a function of shoulder width when the effect of ADT and commercial driveways is removed in the two highest ADT ranges.