An Analysis of High Accident Rates

H. H. Blindauer, Graduate Assistant

and

H. L. Michael, Assistant Director
Joint Highway Research Project
Purdue University

With the advent of the automobile as a mode of transportation late in the nineteenth century, a new phenomenon, the motor vehicle accident, appeared on the American scene. While the motor vehicle was in its early stages of development, the problem was not serious. However, as the volume of cars on the highways increased, the number of accidents increased also; the problem began to assume greater and greater proportions. Today many millions of accidents occur each year, resulting in nearly 40,000 deaths and costing the American economy more than $4 billion.

Three elements contribute to automobile accidents; the driver, the vehicle, and the highway. Quite obviously, the highway engineer does not have complete control over the first two elements since driver characteristics are the result of individual characteristics and may be subject to change by education and enforcement, and vehicle characteristics are primarily controlled by the automotive industry and public desire. The highways, however, are the responsibility of the members of the highway engineering profession, and it is also the responsibility of this group to make them as safe as possible for all drivers. In view of the ever increasing number of accidents on American highways, the highway engineer has many opportunities to contribute to safer highways.

The year 1956, with the passage of the Interstate Highway Act, produced a concerted effort to build safety into highways; but the 41,000 miles comprising the Interstate Highway System is only slightly more than one per cent of all roads in the United States. Even after this vast system of superhighways is built, a large percentage of the remaining highways will be below acceptable standards. Because, in all probability, there will never be enough money to reconstruct all roads to modern standards, it is up to the highway engineer to make existing highways as safe as possible under prevailing conditions.

However, present highways cannot be made safer in the most efficient manner until more information concerning accidents has been compiled and analysed. At present, most states keep complete files of accident reports, but little has been done in utilizing these reports in accident analyses of sections of highway. This is at least partially due to the fact that accident reports are often inaccurate and incomplete as to location, type of accident, and prevailing conditions at the time of the accident.

The role that highway elements play in contributing to accidents is, at the present time, relatively unknown. Many investigations have been performed in the past attempting to correlate accident rate with such factors as the number of intersections and driveways, horizontal and vertical curvature, road and shoulder width, traffic volume, capacity, structures, number of lanes, grades, and commercial and residential development along the highways.

In general, however, the results of these investigations have been inconclusive, and, in some instances, contradictory. Some results of accident studies have indicated, however, that correlation of accidents with some elements of the highway as specific locations is good and that a study of accident records can indicate this correlation. As a result, this study of high-accident highways in Indiana was begun.

In this study, all sections of highway investigated were two-lane highways in rural areas. Two-lane rural highways were selected because a large percentage of the highways in Indiana have only two lanes and probably will remain two-lane highways for many years to come and, as a result, the greatest need for research is on this type of facility. Rural highways were selected for this first study because of the relative homogeneity of conditions affecting accidents on these roads.

SELECTION OF TEST ROADS

In the selection of test roads, three criteria were utilized: (1) each of the test road sections should be of sufficient length to present several different subsection accident rates; (2) the overall accident rate on each test road section should be above the average accident rate in Indiana; (3) the test roads should be located throughout the state in order to present a variety of conditions.

Ten rural sections were selected and are shown on a map of Indiana in Fig. 1. They are, with the listing number corresponding to the number on the figure, as follows:

(1) State Road 25—Lafayette to Delphi
(2) U.S. Highway 31—Miami County

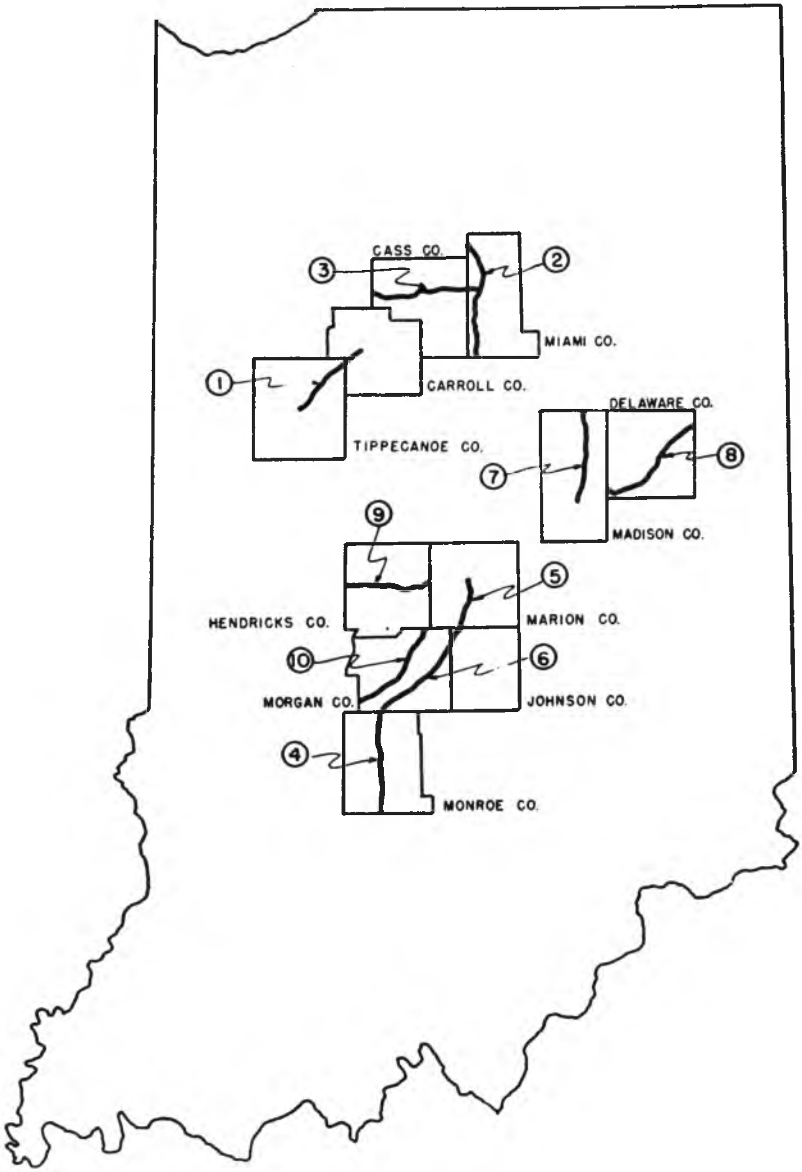

Fig. 1. The ten test sections.

(3) U.S. Highway 24—Burnettsville to Peru
(4) State Road 37—Monroe County
(5) State Road 37—Indianapolis to Johnson—Morgan County Line

(6) State Road 37—Morgan County
(7) State Road 9—Anderson to Madison-Grant County Line
(8) State Road 67—Delaware County
(9) U.S. Highway 36—Hendricks County
(10) State Road 67—Morgan County

Each section was then subdivided into subsections of convenient length, usually one mile. In general, the subsections were numbered by direction from the major town or city on the section with the terminal points of each subsection half-way between integer miles from the city limits. This division was used because most accident reports gave the location of an accident as an integer number of miles from the city limits of the major town or city within the county in which the accident occurred.

COLLECTION OF DATA

It was next necessary to locate as accurately as possible the various major highway elements which might be a factor in accidents, such as private and commercial driveways, intersections, structures, and railroad crossings. This information was used in the data analysis, and it also helped to locate many accidents quite closely since a majority of accident reports not only gave the mileage to the nearest city but also gave a distance from some feature such as an intersection or a structure in the immediate vicinity. A Streetor-Amet Travel Time and Distance Recorder was used in this location phase of the research.

After the highway features on all ten test sections were located and recorded in the proper subsections, the recording of accidents was begun. When this study was initiated, it was planned that the accidents would be recorded according to the type of friction which caused each accident, i.e., intersectional, marginal, medial, or internal stream friction. However, it was found that the accident descriptions on most of the reports were vague and inconsistent, and the data resulting from such a procedure were doubtful as to accuracy.

An approach was used, therefore, which gave reasonably accurate and usable results. The accidents were classified according to the highway features at which they occurred. The classifications used in this study were: (1) accidents occurring at intersections; (2) accidents occurring at structures; (3) accidents occurring at railroad crossings; and (4) other accidents. Structures included all major and minor bridges but not culverts.

All accidents which occurred in the two-year period from January 1, 1956, to December 31, 1957, were recorded according to this classification and, as accurately as possible, by subsection.

Traffic volumes for the ten test sections were obtained from the 1957 Traffic Flow Map of Indiana published by the State Highway Department of Indiana.

ANALYSIS OF DATA

Since the purpose of this study was to determine causes and possible methods for reducing accident rates on specific sections of highway, some method had to be found which would emphasize those subsections having accidents due to assignable causes. It was first planned to utilize correlation and regression in locating assignable causes; but, as the study progressed, another method of analysis was used which presented much better results. That method was statistical quality control.

Statistical quality control has been used for many years in American industry to gauge the performance of men and machines. Control charts with appropriate control limits give a good indication of variation due to random error alone and variation due to assignable causes. Therefore, it seemed logical that if quality control could gauge the performance of machines, it might also be used to gauge the performance of highways. The idea of using quality control in accident analyses is not entirely new since several applications of this technique in recent years have been reported in the literature and with promising results.

In specific terms, the quality control type of accident analysis is as follows: a section of highway is divided into subsections, and the accidents on each subsection are compiled. The accidents are converted to some standard unit of measure and plotted on a control chart. The appropriate upper control limits are computed and also plotted, and those subsections which are out of control are investigated further for assignable causes. If this method is applied to several sections of highway, as it was in this study, it remains substantially the same with one exception; the sections are tested first to ascertain whether or not they are in control. All sections in control are tested using the overall average value, and any section out of control is tested separately using its own average value.

It is important to note that even though a large majority of the subsections will be in control, this does not necessarily indicate that there are not present on these segments assignable causes which contribute to accidents. This is especially true for this study because only high-accident highways were considered for analysis.

When the above procedure was applied to this study, one problem immediately arose. What would be a logical standard unit of measure for the four types of accidents? For accidents occurring at intersections, structures, and railroad crossings, the answer was relatively simple. Since all of these types occurred at single points, they could be converted to an element of risk:

$$\text{Element of Risk} = \frac{\text{Number of Accidents of a Class for a Period of Time}}{\text{Total Traffic Volume on Road for the Same Period}}$$

Because the subsections used in this study were generally one mile or less in length, no more than one structure, intersection, or railroad crossing usually occurred in each subsection. In the few subsections where more than one of any of these features occurred, each intersection, structure or railroad crossing was analysed separately if the subsection was out of control.

An additional refinement to the element of risk for intersections and railroad crossings could be made by including in some manner the traffic volumes on cross roads for intersection analysis and the number of trains per day for railroad crossing analysis. These refinements were not incorporated in this study because of the non-availability of traffic volumes on cross roads and of comprehensive information on train movements.

For other accidents, the problem was somewhat different. Since these included accidents due to horizontal and vertical curvature, private and commercial driveways, insufficient pavement and shoulder width, congestion, and other factors, it was reasoned that, in general, they might be more or less uniformly distributed throughout each subsection. Therefore, the question of subsection length arose because, in all probability, accident occurrence on a subsection two miles in length would be greater than on a subsection one-half mile long if similar conditions were present on both subsections. To account for this, it was decided to use vehicle miles travelled on the subsections rather than vehicles in the denominator of the element of risk equation:

$$\text{Element of Risk} = \frac{\text{Number of Accidents of a Class for a Period of Time}}{\text{Total Vehicle Miles Travelled on Road for the Same Period}}$$

With standard units of measure for accidents determined, only one problem remained, that of finding a standard expression for the control limits of the various sections and subsections. In order to find the solution, it was necessary to refer again to quality control as used in industry.

When dealing with fraction defectives, a mean and standard deviation can be computed for the binominal distribution. Although the distribution may be quite skewed, there will be, by chance causes alone, very few points outside the band between the mean minus three standard deviations and the mean plus three standard deviations. Hence, having set such limits, the statistician has a band of normal variability for the statistical measure of interest.

When applied to this study, the statistical expressions are as follows:

$$p_i = \frac{a_i}{n_i}$$

$$\bar{p} = \frac{a_i}{n_i}$$

$$s_i = \frac{\bar{p}}{n_i}$$

$$CL_i = \bar{p} + 3\ s_i$$

Where p_i = the element of risk on any subsection

$\bar{p}$ = the average element of risk on any section or series of sections

a_i = the number of accidents on any subsection

n_i = the number of vehicles or vehicle-miles on any subsection, the unit of measure depending on the type of accident being analysed

s_i = the estimate of the standard deviation of any subsection

CL_i = the control limit for p_i on any subsection

Elements of risk were computed for each section and each subsection for accidents at intersections, at structures, at railroad crossings or at other locations. The analysis of the ten sections revealed that only one of the sections—S.R. 37 from Indianapolis to the Johnson-Morgan County Line for intersection accidents—was out of control. This indicates that there is a strong possibility that accidents are occurring at interesections on this section of highway for some reason other than chance alone. A detailed study of all intersections of this entire road section would be desirable.

All other sections of highway and types of accident were found to be in control, in other words, the numbers and types of accidents occurring on these sections of several miles in length might be due to chance alone and no assignable cause of accidents in indicated for an entire section.

The subsections of each section of highway were next analyzed for accidents at intersections, at structures, at rail crossings, and at other locations by the control chart technique (see Fig. 2). The $\bar{p}$

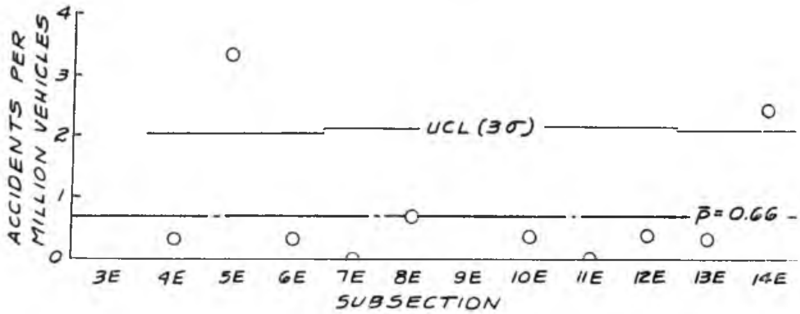

Fig. 2. Portion of control chart for accidents at intersections on Test Section. (SR 25).

value used in each case was the average element of risk for a class of accidents for all subsections of all test sections of highway, except that intersection accidents on out-of-control S.R. 37 just discussed were excluded. The control limits were then computed for each subsection and the results plotted on control charts for each section. The number of accidents was also plotted for each subsection. If the plotted point was below the upper control limit the subsection was in control. If the point was above the control limit, the subsection was out of control. In other words, there was a good probability that accidents were occurring in this subsection because of some assignable cause in the subsection. Such analysis revealed the following:

a) for accidents at intersections, 15 out of 188 subsections were out of control
b) for accidents at structures, 6 out of 73 subsections were out of control
c) for accidents at rail crossings, 1 out of 10 subsections was out of control
d) for other accidents, 11 out of 207 subsections were out of control.

SEARCH FOR ASSIGNABLE CAUSES

After the out-of-control subsections were located by visual inspection of the control charts, it was necessary to reappraise the accidents on those subsections in an attempt to find assignable causes.

Again utilizing the accident reports for the years 1956 and 1957, collision diagrams were made for all intersections, structures, railroad crossings, and other locations of accidents within the out-of-control subsections.

From this final accident analysis, it was possible at a number of the locations to isolate features which caused or contributed to the occurrence of accidents. All out-of-control locations were also investigated in the field to find what conditions existed which were hazardous to motorists, and what remedial measures could be taken to reduce the accidents at those locations.

The search for assignable causes was very profitable. Assignable causes of accidents were found on 86 per cent of the out-of-control subsections, and no assignable cause could be found on only 14 per cent of the out-of-control subsections. Five examples are given in the following paragraphs to illustrate the effectiveness of this analysis technique in the location of assignable causes for accidents.

Fig. 2 shows a portion of the control chart for accidents at intersections for S.R. 25 from Lafayette to Delphi. Two subsections are out of control—subsections 5E and 14E.

The intersection in Subsection 5E is the intersection of S.R. 25 and S.R. 225 about 5 miles northeast of Lafayette. Fig. 3 is a collision diagram of all accidents at that intersection. Note that of ten accidents at this location, eight were rear end collisions with vehicles

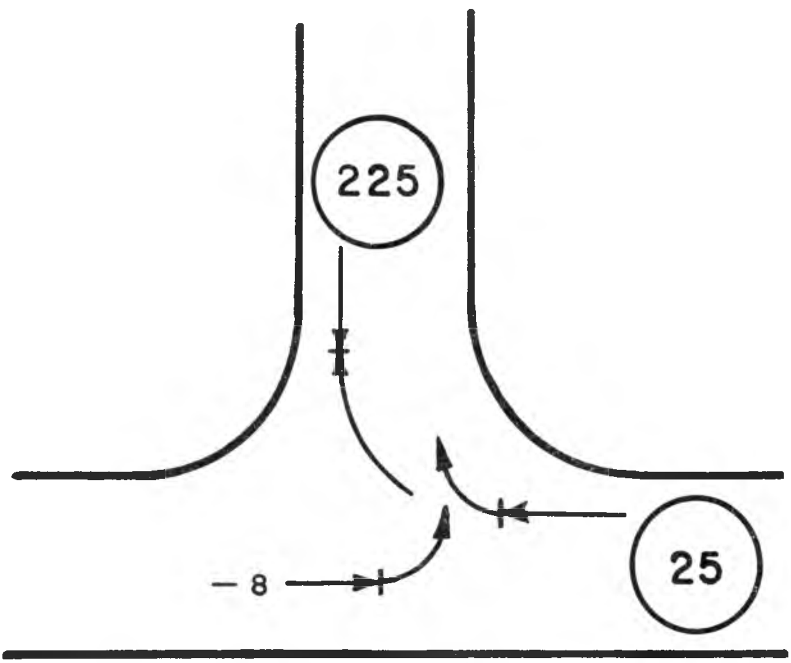

Fig. 3. Collision diagram at the intersection in Subsection 5E of Test Section 1 (Intersection SR 25 and SR 225).

waiting on S.R. 25 to turn left on to S.R. 225. An inspection of the intersection revealed the fact that this intersection is not readily visible to traffic approaching the waiting vehicles because of alignment and grades near this intersection. The recommendation at this site was to install a "Side Road" sign west of the intersection and to construct a refuge lane for vehicles wishing to turn left.

The intersection in the other out-of-control subsection (14E) is the intersection of S.R. 25 and U.S. 421 at the southeast edge of Delphi. The collision diagram for this intersection is shown in Fig. 4.

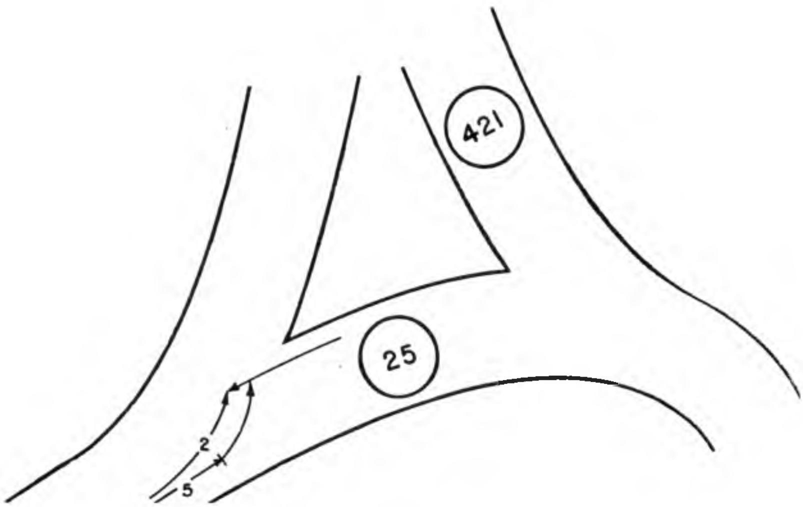

Fig. 4. Collision diagram at the intersection in Subsection 14E of Test Section 1 (Intersection SR 25 and US 421).

The flat angle of divergence which must be used by vehicles wishing to turn left from S.R. 25 to U.S. 421 resulted in head-on collisions

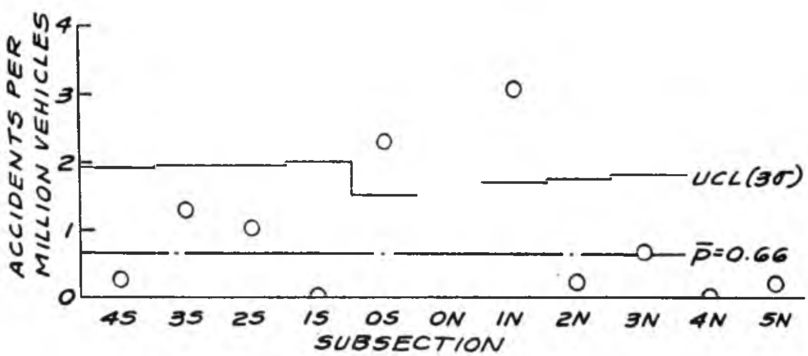

Fig. 5. Portion of control chart for accidents at intersections on Test Section 10 (SR 67).

(two accidents) with vehicles coming from Delphi and rear-end collisions with vehicles travelling east on S.R. 25 (five accidents). The recommendation here was to construct a channelized T intersection which would include a refuge lane for the left turning vehicles.

A portion of the control chart for intersections for S.R. 67 in Morgan County is shown in Fig. 5. Subsection 1N is one of two which is out-of-control. The intersection in this subsection is the intersection of S.R. 67 and S.R. 39 north of Martinsville.

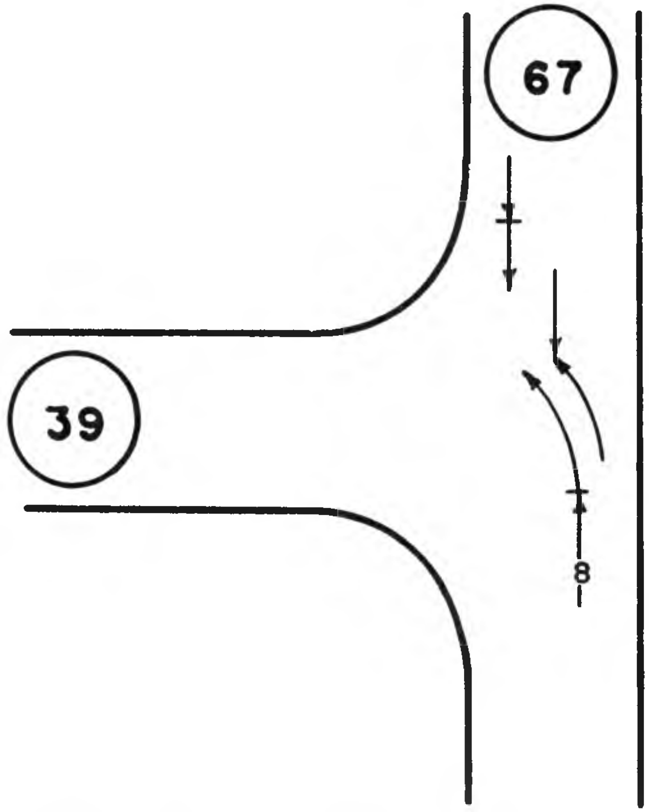

Fig. 6. Collision diagram at the intersection in Subsection 1N of Test Section 10 (Intersection of SR 67 and SR 39).

The collision diagram of this intersection is shown in Fig. 6. Eight of the ten accidents were similar, and occurred because of lack of visibility south of this intersection coupled with an inconspicuous warning sign of the intersection. The recommendation was made to install an oversize "Side Road" sign south of the intersection and to construct a refuge lane for the left turning vehicles.

The control chart for accidents at structures on S.R. 25, Lafayette to Delphi, is shown in Fig. 7. One subsection (1E) is out-of-control.

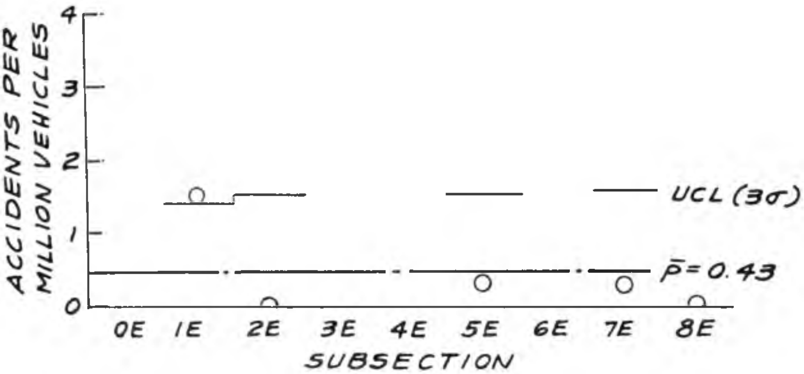

Fig. 7. Portion of control chart for accidents at structures on Test Section 1 (SR 25).

The structure is the new bridge over Wildcat Creek just north of Lafayette. It is of excellent width; observation would lead one to conclude that elements at this structure are safe. The collision diagram (Fig. 8) indicates, however, that the nearness of the side road at one

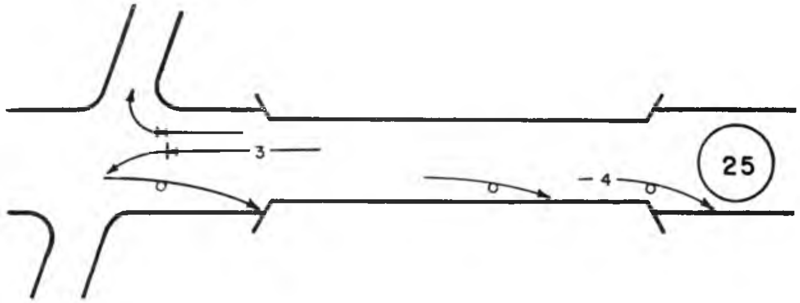

Fig. 8. Collision diagram of the structures in Subsection IE of Test Section 1 (Bridge over Wildcat creek on SR 25).

end of the bridge is resulting in rear-end collisions between vehicles turning left and others travelling south from Lafayette. Six one car accidents have also occurred at the bridge which involved vehicles travelling north. Closer investigation revealed that these latter accidents occurred when the temperature was near the freezing point. Recommendations included quick deicing maintenance on the bridge and warning signs of the side road.

A portion of the control chart for accidents at structures on U.S. 24 from the White-Cass County Line to Peru is shown in Fig. 9. Sub-

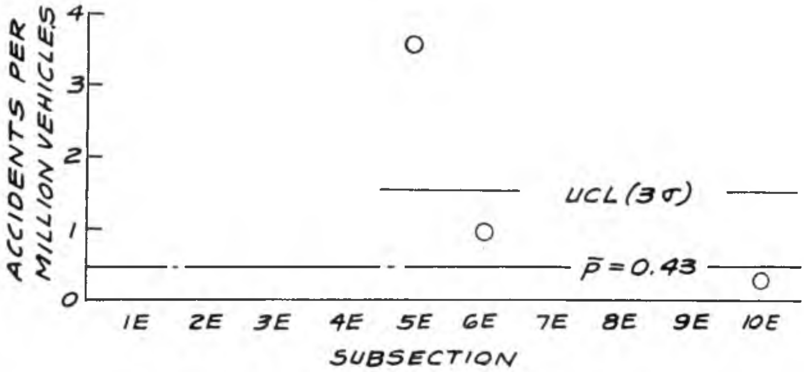

Fig. 9. Portion of control chart for accidents at structures on Test Section 3 (US 24).

section 5E is out-of-control. The structure in this subsection is the overpass separating U.S. 24 and the Wabash Railroad. All 11 accidents occurred at the structure. The extremely narrow width of this structure coupled with bad horizontal and vertical curvature west of the structure are undoubtedly the causes. Reconstruction and relocation are the solutions here, but a speed zoning of U.S. 24 in this vicinity was recommended for the present.

These are only a few examples of the results found in this study, but they do show that here is a statistical tool that is useful in locating accident-prone highway locations. They also indicate that assignable causes subject to elimination can be found rapidly and efficiently at many of the high accident locations.

EDITOR'S NOTE

One of the authors of the preceding paper experienced an unusual incident related to the subject material of the paper and because of its interest it is included here.

A few days after presenting the paper at the 45th Annual Purdue Road School, one of the authors in the company of friends who had read the newspaper account of the paper was travelling to a city some distance from Lafayette, Ind. The road on which they were travelling was one of those included in the study and several discussions about the hazardous locations on that highway occurred as they approached them.

As they approached a T intersection on Test Section 3 at which a large number of accidents had occurred, the author made a remark of that fact to his colleagues. He further explained as they approached the intersection (the intersection of U.S. 31 and U.S. 24 at the west edge of Peru) how most of the accidents resulted between westbound vehicles on U.S. 31 turning left (to go south without stopping as they are directed) in front of eastbound vehicles on U.S. 24 (who are supposed to stop). They were travelling east on U.S. 24 and another vehicle approached the intersection from the east as they halted at the intersection. There was sufficient time for them to continue so they moved forward. As they left the intersection the author, who was looking back, saw the exact type of collision he had just described as a vehicle which had been following his own stopped at the intersection and then pulled in front of the westbound vehicle turning left to go south on U.S. 31. Fortunately the damage was slight.

A recommendation to correct this situation at this intersection was made to the State Highway Department and they are now drafting plans for the channelization and signalization required.

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