variables. Solutions to the problems, which have been reemphasized here, should be of top priority for both the engineers and the researchers who work on roadside safety.

ACKNOWLEDGMENTS

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# Evaluation of Highway Safety Projects Using Quality-Control Technique

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**Highway improvement projects are generally aimed at alleviating highway deficiencies related to traffic flow, congestion, and safety. Although significant effort is expended in developing and implementing the most appropriate countermeasures for specific deficiencies, not enough work is undertaken by highway agencies to evaluate the impact of such improvements. The evaluation of implemented projects is critical in determining future courses of action for the agencies regarding specific countermeasures related to individual problems. Although statistical methods of analysis using Poisson and chi-square distributions have been in existence, they are neither suitable for locations with very low accident frequency nor responsive to local conditions or standards. This paper offers an alternative procedure—quality-control technique—that overcomes the shortcomings of the other methods and offers the advantages of performing parametric comparisons by facility type or improvement type utilizing various measures of effectiveness. This procedure can also be adapted for identification of safety deficient locations. Parametric control charts required for this procedure can be readily prepared by computer or manual methods from existing data for various facility types.**

Increased highway travel during the past decade has resulted in increasing numbers of accidents and fatalities. However, due to higher traffic volumes on the highways, the accident rate is not increasing (1). Recent emphasis on various highway safety programs is believed to have contributed to decreasing the rate of highway accidents and fatalities. Decisions on whether to continue, delete, or improve various highway safety programs depend on the ability to measure their individual effectiveness. While overall program evaluations are done at the state and federal levels, the evaluation of specific projects and treatments at the local level is often neglected. Hence, program evaluation is often subjective and based on limited data.

A comprehensive traffic engineering project was initiated in Oakland County, Michigan, to assess the current status of traffic engineering activities and to develop and implement appropriate projects for the promotion and improvement of traffic engineering activities to reduce the safety deficiencies. As a part of the project, a need was established indicating that a simplified and practical methodology for the evaluation of highway safety projects is necessary. Furthermore, this methodology must be in a suitable format to encourage increased usage by the traffic engineering personnel in the county.

This paper presents the evaluation methodology developed as a part of the comprehensive traffic engineering project and demonstrates its applicability by performing a typical highway safety project evaluation. That part of the evaluation methodology, which is reported in this paper, relates to the parametric comparison of highway accident experiences.

## EXISTING PARAMETRIC TEST PROCEDURES

Determining the significance of highway improvements requires the evaluation of the effect of specific projects or treatments on accident experience, other measures of effectiveness, or both. A small change in accident experience can be called a matter of chance, whereas a large reduction is generally attributable to the specific improvement.

There are currently two basic methods of testing the significance of a change: the Poisson and the chi-square tests of significance. The first test involves measuring the change in accident experiences and comparing it with a set of Poisson significance curves developed for a specific range of confidence intervals (2). A change greater than the minimum percent change necessary for the corresponding accident frequency at a given level of confidence limit is interpreted as a significant improvement. The tests of means and the distributions are described as conservative and liberal measures of significance respectively (see Figure 1). For example, if the intersection point of the number of before accidents at the study site and percent reduction during the post-improvement period is above the top curve, it can be stated that the null hypothesis can be rejected at the given level of confidence. In this case, the null hypothesis is that there is no difference between the pre- and post-improvement accident experiences. When accident data for a specific project fall between the two curves (conservative and liberal), the significance of the improvement is not conclusively demonstrated; more data are necessary to obtain a more specific conclusion.

The chi-square test is similar to the Poisson test in that two curves are used to represent the limiting conditions (Figure 2). The liberal curve is based on the Poisson distribution and minimizes the probability of judging a reduction as nonsignificant when in fact it is really significant. The conservative curve is based on the chi-square distribution and serves to minimize the probability of defining a reduction as significant when the opposite is true (3).

**Figure 1. Poisson curves for test of significance in accident reduction.**

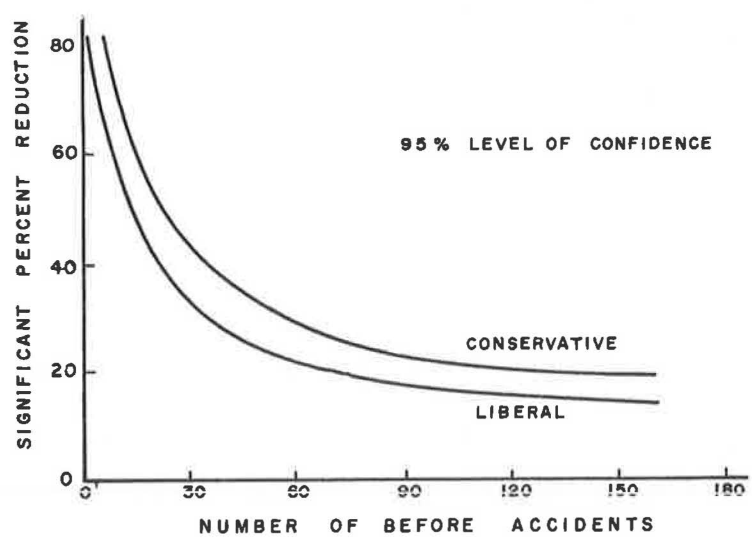
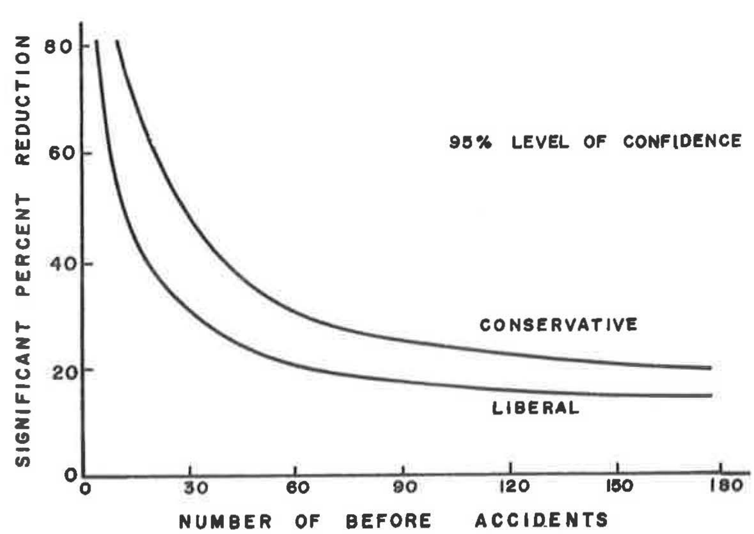



**Figure 2. Chi square curves for tests of significance in accident reduction.**



These two techniques can provide an adequate method of testing the significance of a safety improvement when the magnitude of a pre-improvement accident frequency is sufficiently high. As the accident frequency decreases, a higher accident reduction percentage is necessary to attribute the accident reduction to the specific improvement. This point can be demonstrated by using significance curves shown in Figure 2 (4). Suppose that a safety improvement were performed at a location where the preproject accident data indicated an average of 10 collisions per year. Looking at the significance curves, we can observe that the improvement must reduce accidents to three or four per year before it can be called statistically significant. Thus, a very high reduction in accidents is required to show a statistically significant change resulting from the improvement.

Classical quality-control theory has been applied to manufacturing processes in the past. In the field of highway safety, a similar approach has been used in the identification of hazardous locations. Jorgenson (2) has presented the rate quality-control method as one method for the identification of hazardous locations.

The methodology used in the evaluation procedure presented in this paper uses similar quality-control theory. This procedure involves determining accident experience averages and upper confidence limits for groups of similar highway locations at selected levels of confidence. The upper confidence limit (UCL) of group i is defined as

$$UCL_i = \bar{X}_i + Z\sqrt{\sigma_i^2} \quad (1)$$

where

$\bar{X}_i$ = average frequency of accidents for group i,
$\sigma_i^2$ = variance of accident frequency in the same group i, and
$Z$ = constant used to define selected confidence level.

The similarity in highway locations can be dependent on several variables. In this study the number of lanes and demand volumes—i.e., average daily traffic (ADT)—were used to classify the highway locations. The selection of classification variable increments depends on sample size and ability of the independent variables to explain the variability in the dependent variable, in this case, accident experience.

The highway locations within each category (number of lanes and demand) that fall above the upper confidence limit line are defined as abnormal or out of control when compared with its group. Such abnormal sites are candidates for improvements. If a location indicates a pre-improvement accident frequency falling into the abnormal category and post-improvement accident frequency under the upper confidence limit, it would indicate that the applied treatment was successful in bringing the site from out of control to within control. Thus, it can be concluded that the treatment was effective in alleviating the accident problem.

Groups of highway locations will range from low to high accident frequencies and from low to high traffic volumes. Each group has its own mean and variance from which upper confidence limits are determined. Therefore, evaluation of a site that has very low accident frequency and also has very low traffic volume can be out of control within its own group and, as a consequence of safety treatment, can be within control after improvement.

The resulting increases in traffic volume from an improvement may change the group to which a location is classified, but it is still possible to determine whether or not it is within control by using a different quality-control chart.

For example, Figure 3 shows hypothetical confidence bands for four-legged unsignalized intersections with two lanes on each approach. The horizontal axis indicates increasing groups of approach traffic volumes. The vertical axis represents total accident frequency, which will be the measure of effectiveness in this sample. The upper limits of the band, $Y_3$ - $Y_4$, $Y_7$ - $Y_8$, and $Y_{11}$ - $Y_{12}$, represent 95 percent confidence limits for the distribution of accident frequencies observed in the various volume groups. The total accident frequency at the test site before the safety improvement is indicated by point $Z_1$. Consider that the post-implementation accident experience results in a shift in total accident frequency to $Z_2$ or $Z_3$. The movement of the site from $Z_1$ to $Z_2$ indicates the site was out of control before the safety improvement and is in control after improvement; however, the location remained in the same group of traffic volumes. Similarly, consider that point $Z_1$ shifted to $Z_3$. This shift indicates only a minor reduction in total accident frequency. However, it indicates that the location is in control in a different volume group; thus, the reduction can be considered statistically significant at the 95 percent level of confidence.

By employing this technique, it is possible to evaluate the change in accident experience resulting from improvements and to compare the improved facility with similar locations. This, coupled with the technique's ability to measure the improvements on low as well as high frequency locations, provides a valuable tool in the overall highway safety evaluation strategy.

## STUDY AREA

Oakland County is located in southeastern Michigan. The county has 39 cities and villages and 22 townships; it is one of the most rapidly growing counties in the Detroit metropolitan area. It has a population of over 900 000 and an area of 2408 km² (867 miles²) with approximately 7500 km (4500 miles) of highway network.

A computerized accident record system has been established for the county that analyzes a preselected set of links and intersections on an annual basis for accident frequency, accident rate, and accident type. The accident rate is computed in customary units to reflect accidents per million vehicle-miles for roadway sections and accidents per million vehicles for intersections.

There were 1205 links in the system that experienced one or more accidents in 1975. These links vary from two-lane roadways to freeway links. The overall ranking of these links on the basis of accident frequency

Figure 3. Hypothetical confidence bands for unsignalized intersections.

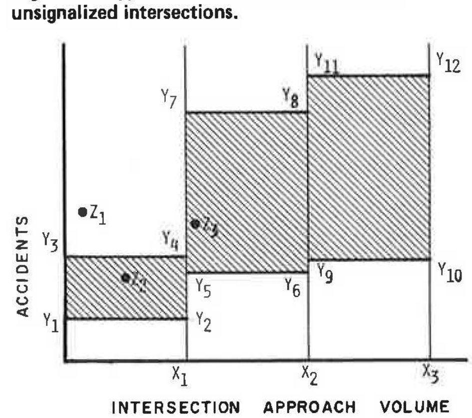


Table 1. Accident characteristics for various link types.

| Roadway Link Type | No. of Links in Group | Maximum Accident Frequency | Maximum Accident Frequency/Mile | Maximum Accident Rate/MVM | Minimum Accident Frequency | Minimum Accident Frequency/Mile | Minimum Accident Rate/MVM | Mean Accident Frequency | Mean Accident Frequency/Mile | Mean Accident Rate/MVM | Standard Deviation Accident Frequency | Standard Deviation Accident Frequency/Mile | Standard Deviation Accident Rate/MVM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Freeway | 41 | 65 | 60 | 3.57 | 3 | 3 | 0.41 | 22.1 | 17.1 | 1.31 | 13.8 | 12.2 | 0.67 |
| 6 or more lanes | 39 | 177 | 188 | 12.56 | 16 | 17.8 | 1.03 | 84.9 | 80.5 | 4.7 | 38.2 | 36.8 | 2.5 |
| 5 lanes | 46 | 146 | 146 | 17.12 | 2 | 2 | 1.72 | 49.9 | 45.8 | 5.7 | 36.0 | 31.0 | 3.23 |
| 4 lanes | 119 | 242 | 143.33 | 29.39 | 2 | 1.2 | 0.15 | 42.8 | 37.4 | 5.5 | 40.2 | 31.0 | 4.4 |
| 2-lane, 2-way | 919 | 126 | 115 | 277.17 | 1.0 | 0.33 | 0.20 | 13.52 | 12.03 | 10.24 | 18.45 | 16.8 | 16.2 |

Table 2. Accident characteristics for 2-lane, 2-way facilities.

| Demand Level (ADT) | No. of Links in Sample | Mean Accident Frequency | Mean Accident Frequency/Mile | Mean Accident Rate/MVM | Standard Deviation Accident Frequency | Standard Deviation Accident Frequency/Mile | Standard Deviation Accident Rate/MVM |
|---|---|---|---|---|---|---|---|
| 0-4 000 | 495 | 4.1 | 3.16 | 14.5 | 4.94 | 3.68 | 20.9 |
| 4 001-8 000 | 140 | 13.4 | 11.3 | 5.4 | 8.2 | 6.98 | 3.36 |
| 8 001-12 000 | 129 | 19.2 | 17.6 | 5.0 | 14.89 | 12.23 | 3.3 |
| 12 001-16 000 | 62 | 27.36 | 25.44 | 5.07 | 16.05 | 13.98 | 2.74 |
| 16 001-20 000 | 48 | 40.77 | 36.1 | 5.63 | 24.12 | 17.87 | 2.87 |
| 20 001-24 000 | 23 | 50.27 | 49.24 | 6.17 | 20.02 | 19.48 | 2.57 |
| 24 001-28 000 | 22 | 66.19 | 63.45 | 5.82 | 28.36 | 26.2 | 2.63 |

or rate does not necessarily reflect their hazardousness relative to their characteristics. It was recognized that the number of lanes in the links represents a significant distinguishing feature that may influence differences in accident experience.

## Objectives and Procedure

The objectives of this study were:

1. Determine whether or not there is significant difference in accident patterns between various types of links, e.g., two-lane, four-lane, five-lane, and freeway;
2. Develop quality-control charts so that highway link locations which are abnormal in terms of accident experience can be recognized; and
3. Test whether the quality-control charts can be used in the evaluation of safety projects.

In order to accomplish the above objectives, an analysis of the available accident data for the county was performed. The analysis consisted of a two-step procedure. First, all 1205 links were stratified according to the number of lanes and types of facilities, which yielded the following groups:

| Type of Links | Number in Group | Type of Links | Number in Group |
|---|---|---|---|
| Freeway | 41 | 5-lane | 46 |
| 6 or more lanes for highways without access control | 39 | 4-lane | 119 |
| | | 3-lane | 1 |
| | | 2-lane | 919 |
| | | Unknown | 40 |

The "unknown" category means an absence of lane number information in the data file. The three-lane category was eliminated from further analysis due to insufficient data points.

The accident experience of each group was statistically analyzed to determine the maximum value, minimum value, mean, and standard deviation. In each case, the various measures of accident experience were analyzed (i.e., accident frequency, accident frequency per mile, accident rate). The results of this analysis are shown in Table 1. The resulting data indicate that there is a substantial difference in mean accident frequencies and mean accident rates between the link types: freeway links have the lowest accident rates, and two-lane roadway links have the highest accident rate.

In the second step, the data files for two-lane roadway facilities were then segregated on the basis of traffic demand (ADT) data in order to study the variations of accident experience as a function of traffic demand. Several different increments of demand were used to substratify the two-lane, two-way facilities. Table 2 presents data classified using 4000 ADT as the demand increment for two-lane, two-way roadways only. These data clearly show that there is a steady increase in mean accident frequency for increased ADT.

The upper limits of the various demand groups were computed using standard statistical tables for 80 percent, 84.13 percent (1 standard deviation), 90 percent, and 95 percent confidence levels. These limits of the confidence level were then determined by using standard (Z) one-tailed distribution values from statistical tables. They indicate that a particular link will be under the upper limit of its appropriate category, the percent time indicated by the confidence level. The selection of higher confidence levels will mean more stringent criteria for identifying a specific location as critical.

## Results

The two-lane roadways were segregated by demand groups. The mean frequency lines and the upper confidence limit lines were generated for all groups of demand, and then appropriate quality-control graphs were prepared (Figures 4-7).

Figure 5 presents the mean frequencies and one standard deviation line for various volume groups. Figures 4, 6, and 7 show 80 percent, 90 percent, and 95 percent confidence levels respectively. They represent increasingly stringent criteria for finding statistically significant results from safety projects.

These charts can be used to determine the hazardousness of a location. A location plotted on the appropriate chart falling above the mean value line may indicate a somewhat abnormal accident experience, since its accident experience is above the mean experience of the group. Those values falling above the confidence limit lines would indicate locations that are critical or out of control.

In an evaluation study, if it is found that a location was out of control before the treatment was applied and comes under control either in the same volume group or in a different volume group, then safety improvement has been achieved. This type of quality-control chart can be developed for various categories of accidents and can be used to test specific evaluation objectives.

The quality-control charts shown here (Figures 4-7) are for a highway network in a specific area (Oakland County, Michigan). The same charts may not be applicable in other areas. Therefore, quality-control charts may have to be developed for a specific area on the basis of existing areawide accident experience before they can be used for evaluating highway safety projects in the area.

## CASE STUDY

In order to demonstrate the use of the quality-control procedure in the evaluation of a highway safety project, an improvement site was selected for evaluation. The site chosen was a 3.2-km (2-mile) stretch of two-lane roadway that was outmoded due to the land use development and resulting increased traffic demand and high accident experience. In an attempt to alleviate the congestion problem and reduce the accident experience, the

Figure 4. Quality-control graph for confidence level 80 percent.

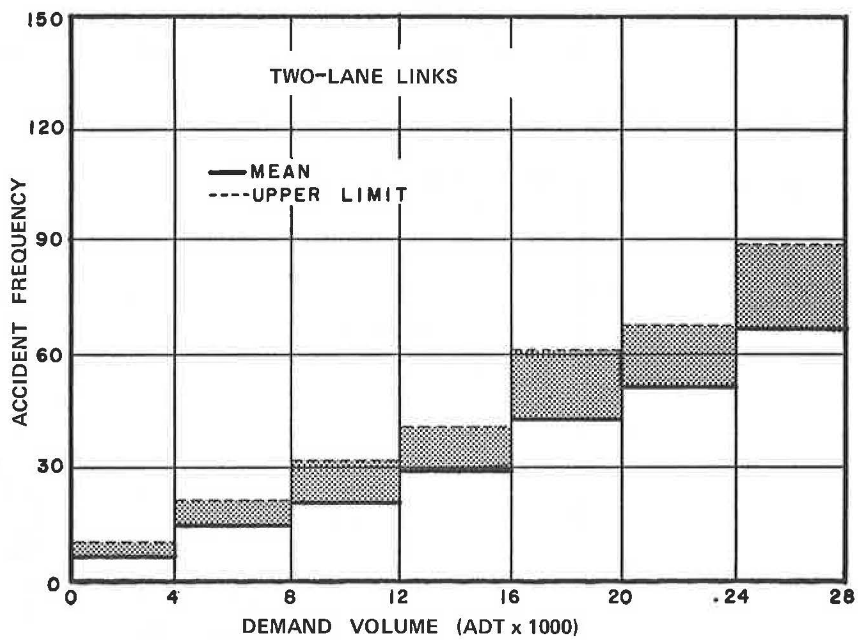



Figure 5. Quality-control graph for confidence level 84.13 percent.

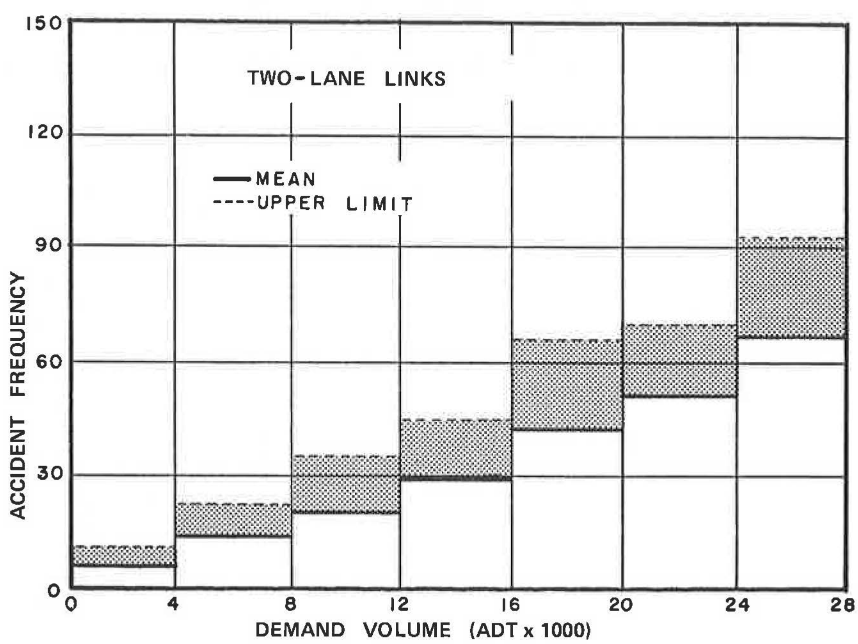


Figure 6. Quality-control graph for confidence level 90 percent.

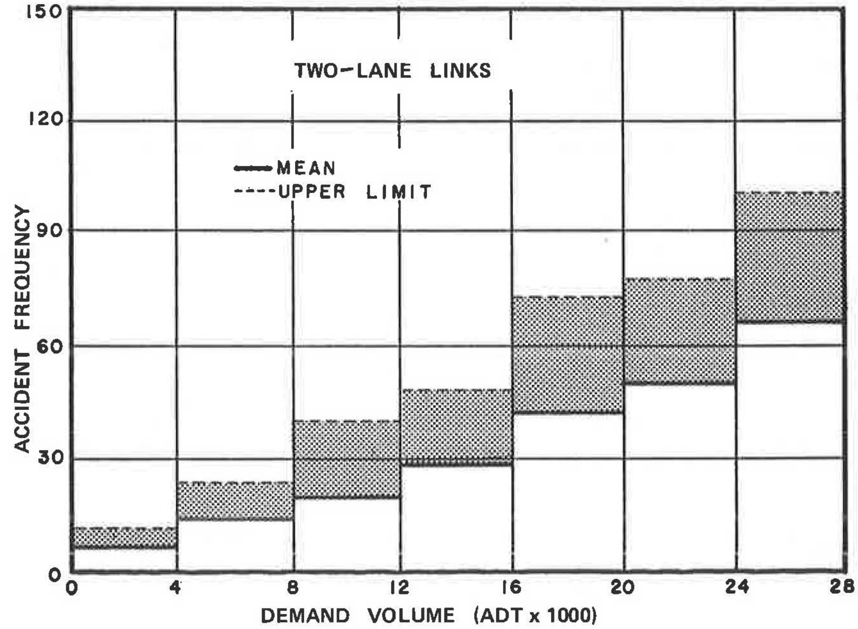
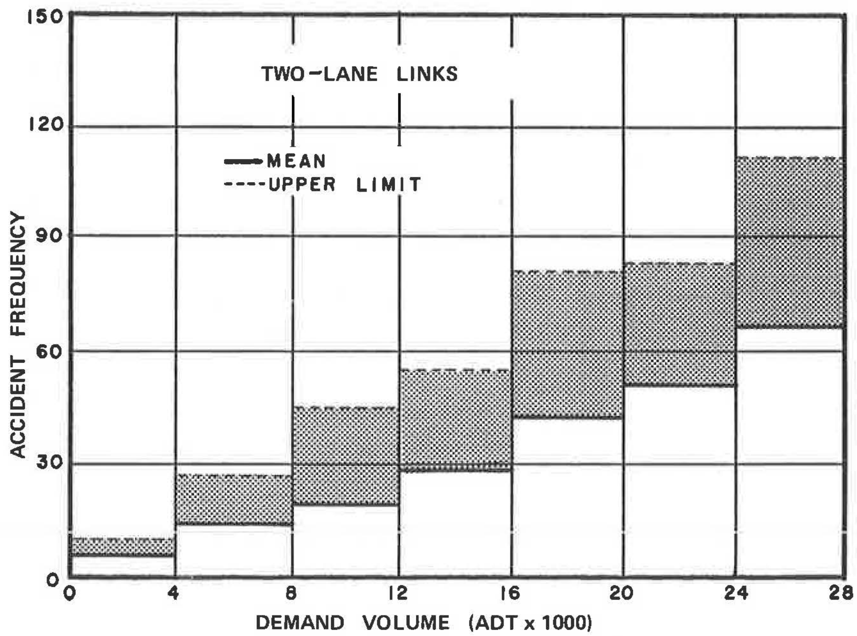



Figure 7. Quality-control graph for confidence level 95 percent.




roadway was widened to a four-lane facility. The volume and accident data available for this study were as follows:

| | Traffic Volumes | | | |
|---|---|---|---|---|
| | Pre-Project | | Post-Project | |
| Link Number | 1973 | 1974 | 1975 | 1976 |
| 1 | 12 000 | 14 000 | 25 000 | 27 000 |
| 2 | 13 000 | 15 000 | 26 000 | 29 000 |

The accident experience in the above locations was as follows:

| | Traffic Accidents (yearly) | | | |
|---|---|---|---|---|
| | Pre-Project | | Post-Project | |
| Link Number | 1973 | 1974 | 1975 | 1976 |
| 1 | 54 | 44 | 55 | 47 |
| 2 | 79 | 65 | 64 | 50 |

Averages for use in the evaluation study were computed as:

| Pre-Project Data | Post-Project Data |
|---|---|
| Link 1 Volume = 13 000 ADT | Link 1 Volume = 26 000 ADT |
| Accident Frequency = 49 | Accident Frequency = 51 |
| Link 2 Volume = 14 000 ADT | Link 2 Volume = 27 500 ADT |
| Accident Frequency = 72 | Accident Frequency = 57 |

When the pre-project data are plotted on the quality-control graph pertaining to the 95 percent confidence level (Figure 8), it can be seen that link 2 was out of control. The improvement to four lanes resulted in a change in volume and accident experience. Since the link is now a four-lane facility, a different quality-control graph (Figure 9) must be used for post-project evaluation. When these data are plotted on Figure 9, it can be readily seen that the post-accident experience is below the mean accident frequency for the appropriate

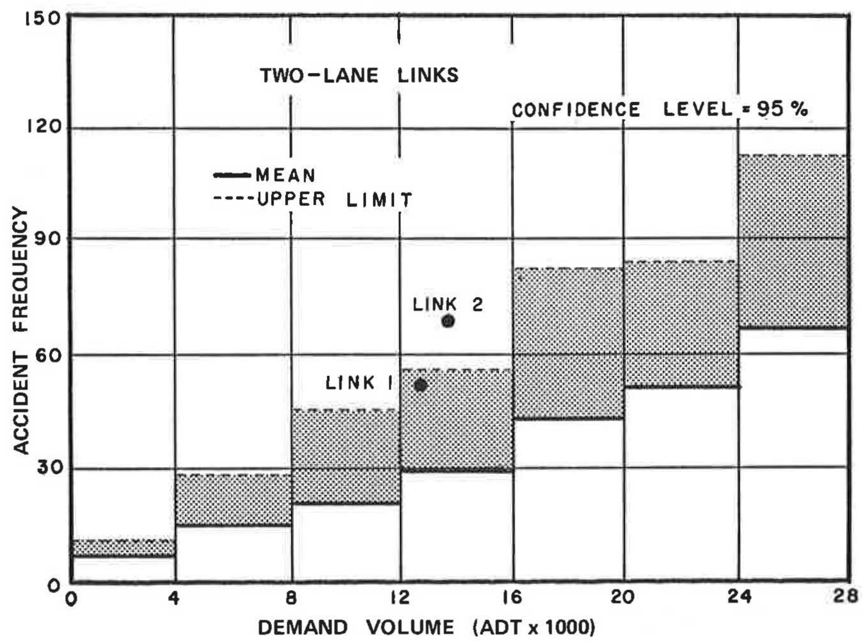



Figure 8. Case study application of quality control graph (2-lane, 2-way facility).

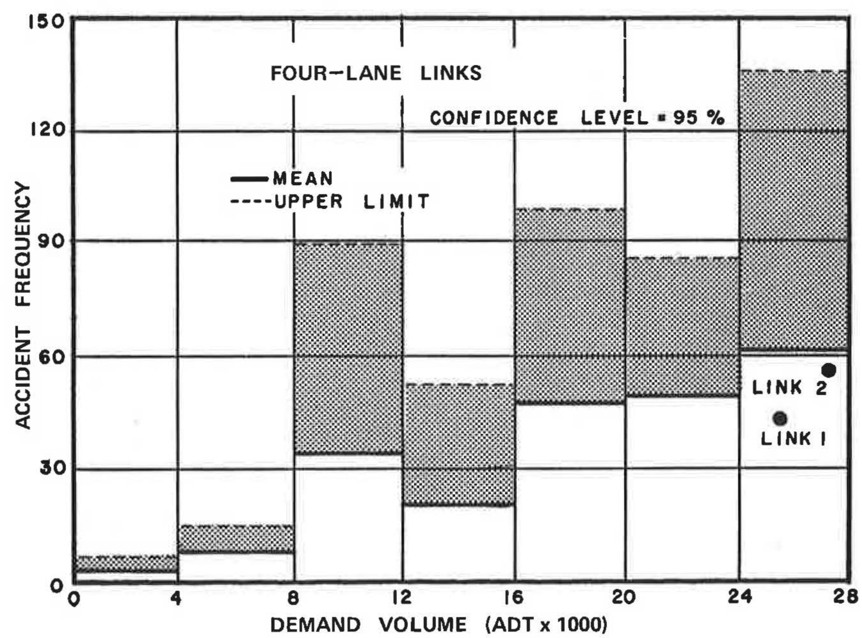



Figure 9. Case study application of quality control graph (4-lane, 2-way facility).

volume group; therefore, it can be concluded that the improvement has had a significant impact on the accident experience.

## CONCLUSIONS

The quality-control technique yields a method of determining the statistical significance of safety improvement projects that is not only responsive to low accident frequencies but is also representative of local conditions and standards. The necessary quality-control charts are easily generated using available data for specific areas. The development of appropriate quality-control charts for various facilities and accident types will allow the evaluation of various highway safety improvements.

The study indicated that there is considerable difference in accident experience between types of highway facilities, such as freeway, two-lane, four-lane, five-lane, and six-lane. The data also indicated that the accident experiences change with a change in traffic volume.

Quality-control charts may be developed for various levels of traffic demand for all types of roadway, if there are sufficient data points available. The choice of traffic volume increments should be made by analyzing various grouping schemes and observing the accident distribution characteristics. The quality-control charts can be used to identify specific highway locations as abnormal or critical, depending on their location with respect to the confidence bands.

The example cited demonstrates that it is possible to use quality-control charts for evaluating a highway safety improvement or project. It provides a way to evaluate highway safety projects that involve low accident frequencies, since the procedure only recognizes out-of-control and in-control situations. It also assists the evaluators in determining whether significant improvements have taken place.

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# Michigan Dimensional Accident Surveillance (MIDAS) Model: Progress Report

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**The Michigan Dimensional Accident Surveilance Model is being developed by the Michigan Department of State Highways and Transportation. The model aims to objectively analyze the entire roadway system (not just locations with the worst accident histories), to select candidate locations for upgrading that are the most sensitive to correction, and to choose sets of the most likely cost-effective corrective measures. This paper introduces the procedures; reports on progress, accomplishments, and shortcomings to date; and stimulates related interest and development elsewhere. The model may be visualized as grouping all roadway segments with identical predetermined physical and accident characteristics into one cell of a multicell array. Subsequent statistical analysis, cost estimating, and accident predictions assess probable impacts on transforming all sites from one cell type to another. Data sources are several master tapes of accident reports, road features inventory files, and a traffic volume file. The identification of segments having a statistically significant number of accidents and the determination of logical countermeasures work well. The prediction of expected accidents for each corrective action at present lacks precision and requires additional work.**

The Michigan Department of State Highways and Transportation has maintained computerized accident report data since 1963. Candidate locations for possible spot safety improvements were selected, in rank order, by total accidents and accident rates for 0.3-km (0.2-mile) roadway segments. Threshold values were used to control the size of the listing. The sam- locations tend to appear year after year. Feasible corrective treatments are eventually exhausted. Yet engineering attention is still given, although lower ranked candidate sites may not be investigated due to limitations of time, personnel, and funding.

## MODEL DEVELOPMENT

A desire to identify sites with correctable accident patterns (independent of the number of total accidents) initiated the development of an accident analysis system—the Michigan Dimensional Accident Surveillance (MIDAS) model. The guiding objectives for model development are to

1. Greatly expand knowledge by including as much pertinent information as possible in the analysis;
2. Analyze objectively the entire roadway system, not just locations with poor accident histories;
3. Optimize injury avoidance;
4. Select candidate locations that are the most sensitive to correction and select sets of corrective measures that are likely to be the most cost effective; and
5. Provide a managerial tool to test policy.

The model consists of three stages: (a) locating all sites with statistically significant injury accident patterns, (b) investigating all feasible countermeasures, and (c) optimizing expenditures based on cost effectiveness. Due to spatial limitations, this paper will primarily address the progress in developing stage 1.

The principal concept of stage 1 is to aggregate roadway segments with similar physical and environmental characteristics into one cell of a multicell array, with the array containing all conditions in the universe. The dimensions and principal variables are

1. Geometry—number of lanes, horizontal alignment, vertical alignment;
2. Environment—roadside development, day/night, wet/dry, intersection/midblock, operational controls;
3. Cross section—lane width, shoulder width, curb type; and
4. Accident—accident characteristics.

From these variables, it is mathematically possible to create 514 080 data sets. Most of the conditions do not