Analysis of Policies for Safety Improvements on Low-Volume Rural Roadways

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Midwest Transportation Center
Iowa State University
2521 Elwood Drive - Suite 125
Ames, IA 50010
Telephone: 515-294-8103
FAX: 515-294-0467

ANALYSIS OF POLICIES
FOR
SAFETY IMPROVEMENTS
ON
LOW-VOLUME RURAL ROADWAYS

by

David J. Schwartz
James A. Bonneson
Patrick T. McCoy

Final Report

Prepared by
Department of Civil Engineering
University of Nebraska-Lincoln
in conjunction with the
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PREFACE

This report is the product of a research project in the University Transportation Centers Program. The Program was created by Congress in 1987 to "contribute to the solution of important regional and national transportation problems." A university-based center was established in each of the ten federal regions following a national competition in 1988. Each center has a unique theme and purpose. Although all are interdisciplinary and also have education missions.

The Midwest Transportation Center, one of the ten centers, is a consortium that includes Iowa State University (lead institution) and the University of Iowa. The Center serves Federal Region VII which includes Iowa, Kansas, Missouri, and Nebraska. Its theme is "transportation actions and strategies in a region undergoing major social and economic transition." Research projects conducted through the Center bring together the collective talents of faculty, staff, and students within the region to address issues related to this important theme.

The research presented in this report reflects the key mission of the Midwest Transportation Center by examining policies for improving the safety of low-volume roadways. The research was conducted by researchers in the Department of Civil Engineering at the University of Nebraska-Lincoln. Professor Patrick T. McCoy was the Principal Investigator, and Assistant Professor James A. Bonneson was the co-investigator. They were assisted by David J. Schwartz, a graduate research assistant in civil engineering at the University of Nebraska-Lincoln.

ABSTRACT

In order to determine the adequacy with which safety problems on low-volume rural roadways were addressed by the four states of Federal Region VII, a review was made of the states' safety policies. After reviewing literature dealing with the identification of hazardous locations, evaluation methodologies, and system-wide safety improvements, a survey of the states' safety policies was conducted. An official from each state was questioned about the various aspects and procedures dealing with safety improvements. After analyzing and comparing the remarkably diverse policies, recommendations were made in the form of a model safety program. This program included special modifications that would help remediate hazards on low-volume rural roadways. Especially encouraged is a system-wide approach to improvement which would cover all parts of the highway system, not just urban and high-volume roadways.

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INTRODUCTION

BACKGROUND

All state highway transportation agencies have policies for the administration of their highway safety improvement programs. These policies provide guidance for the identification of safety problems, evaluation and selection of improvement alternatives, and prioritization of safety improvement projects. Experience with these policies suggests that some of these policies may tend to favor highway safety improvement projects on high-volume highways to the exclusion of projects on potentially more hazardous low-volume rural roadways. This tendency is generally introduced in the identification of safety problems and the evaluation of improvement alternatives. In both cases, the projects on low-volume roadways may be at a disadvantage because accident history is used as the sole measure of the safety problem. The fact that a particular roadway location is recognized as being hazardous is not sufficient to qualify it for treatment. Moreover, the use of accident history implies that accidents must occur *before* a hazardous location can be addressed by the safety improvement program.

Safety problems are traditionally identified using accident history alone. Since accident frequency is primarily dependent on exposure (*i.e.*, traffic volume), low-volume rural roadways typically have few accidents despite the fact that they may be extremely hazardous. In addition, a high percentage of the drivers on rural low-volume roadways are familiar with the roadways' deficiencies. Consequently, hazardous locations on these roadways may have relatively few accidents because of the extra precautions taken by familiar drivers. Taylor and Thompson (*1*) recognized the shortcomings of basing the identification of hazardous locations solely on accident experience and recommended the use of a hazard index to overcome this deficiency. However, even if a hazard index were used to identify highway safety problems, the policies of most states do not provide for the evaluation and selection of safety improvement projects on the basis of reduction in hazard index.

The evaluation of improvement alternatives may also tend to favor the selection of projects on high-volume roadways. In this regard, most policies have evaluation procedures which are based on a benefit-cost analysis. Benefits relating to hazard in the traditional evaluation procedures are solely dependent on accident history and the accident reduction potential of a given improvement. Therefore, a location on a high-volume highway with many accidents and an improvement expected to reduce a significant proportion of these accidents will show a substantial benefit. In contrast, a location on a low-volume rural roadway with greater hazard but significantly fewer accidents due to low volume and driver familiarity is not likely to show a significant accident reduction benefit. Thus, one shortcoming of the traditional benefit-cost evaluation procedure of most highway safety program policies is that accidents must occur before an improvement can be economically justified regardless of whether the location is known to be hazardous.

The assignment of costs to various accident types may be another way in which safety improvement projects on low-volume roadways are placed at a disadvantage in the evaluation of improvement alternatives. The policies of some states may fail to recognize the greater severity of accidents on low-volume rural roadways as compared to those on higher volume roadways. Some policies may even fail to recognize the differences between urban and rural accidents. Consequently, the benefits of safety improvements on low-volume rural roadways would be underestimated by such policies.

A third aspect of the problem in the evaluation of safety improvement alternatives is the lack of knowledge on the accident reduction potential of safety improvements typically applied to low-volume rural roadways. This problem is the result of the relatively infrequent occurrence of accidents on these roadways as well as the higher priority given to safety research focusing on higher-volume roadways. Thus, the safety benefits of safety improvements on low-volume rural roadways may not be adequately considered.

RESEARCH OBJECTIVE

Each of the four states (*i.e.*, Iowa, Kansas, Missouri, and Nebraska) in the Midwest Region has a highway safety improvement program administered by its transportation agency. Included in the policies of the highway safety improvement program are procedures for identification of safety problems, evaluation and selection of improvement alternatives, and prioritization of safety improvement projects. The objective of this research was to examine the safety improvements programs of the four states in the Midwest Region relative to their consideration of low-volume rural roadways and to recommend policy modifications to improve their consideration of low-volume rural roadways.

RESEARCH APPROACH

The highway safety improvement program policies of the four states in the Midwest Region were determined and examined relative to their consideration of low-volume rural roadways. A review of the literature dealing with highways safety improvement programs and low-volume roads was conducted to provide a frame of reference for the research. In addition, the four states were surveyed to obtain information about the states' highway safety improvement programs and issues pertinent to traffic safety on low-volume rural roadways. Based on this information, a model policy for more effectively incorporating the needs of low-volume rural roadways was developed and modifications to existing policies were recommended.

The literature review is presented in Chapter 2. The survey results are discussed in Chapter 3. The conclusions are recommendations of the research are presented in Chapters 4 and 5, respectively.

Chapter 2

LITERATURE REVIEW

An extensive literature review was undertaken to find information about safety concerns on low-volume roads. Few articles pertained to the safety of low-volume roads per se, but much research has been dedicated to safety, particularly the areas of identifying hazardous locations, assessment of countermeasures, design criteria, and economics of safety policies. The information obtained in the literature review provided a basis for the examination of the state safety improvement program policies.

HAZARDOUS LOCATION IDENTIFICATION

Overview

A hazardous location is one that presents a risk to the driver in terms of high probability of accident occurrence or high accident severity. This risk may or may not be reflected in past accident records.

Most state and local agencies currently use accident records to identify high accident locations. As accident data are extremely sensitive to exposure levels, some agencies supplement accident data with other measures of roadway hazard. In this context, a road section's hazard rating accounts for its accident potential (or risk) and severity which are the truest measures of relative safety among sections.

The identification of a hazardous location is based on a "spot" approach to highway safety improvements. This approach has traditionally been used by almost all agencies. An alternative approach receiving increased attention is the "system-wide" approach to safety improvements. In this approach, problematic elements of the roadway or roadside are identified on a regional basis and corrected uniformly, regardless of the accident experience at any specific location.

Methods of Identifying Hazardous Locations

In the following discussion, a location's hazard ranking for the accident-based methods is calculated by dividing the count of accidents by the measure of exposure (e.g., time, length, volume). In the case of time span or road length, the exposure is predetermined whereas traffic demand is measured to coincide with the other exposure measures.

A. Accident Frequency Method. This method ranks roadway locations by the number of accidents. Those locations with higher accident frequencies are identified as hazardous. The exposure measures used include: (1) length of roadway segment and (2) time span for the accident frequency summary. The advantages of this method are:

- It is the most direct and obvious measure of hazard.
- As improvement effectiveness is typically measured by accidents reduced, the cost-effectiveness of improvement can be quickly assessed and/or evaluated.

However, the method also has a number of disadvantages:

- It may not be the best predictor of hazard (in terms of reliability) due to large variability in accident data and changes in drivers, demand, and geometrics.
- Its accuracy is limited by under-reporting, errors in entering accident report data to the database, difficulty in identifying accident location, and differences in accident cost reporting thresholds among agencies.
- It does not consider traffic demand exposure. Thus, it is not sufficiently sensitive to the relative accident potential among locations.
- It is not sensitive to accident severity.
- Comparison among frequencies (via ranking) is subject to error due to greater uncertainty (higher variability) for higher frequencies.

B. Accident Rate Method. This method extends the accident frequency method by including traffic volume as a measure of exposure. The exposure measures used include: (1) length of roadway segment, (2) time span for the accident frequency summary, and (3) traffic demand. There is one primary advantage of this method:

- It includes traffic demand as an exposure measure.

But, it also has several disadvantages, including:

- It may not be the best predictor of hazard (in terms of reliability) due to large variability in accident data and changes in drivers, demand, and geometrics.

- Its accuracy is limited by under-reporting, errors in entering accident report data to the database, difficulty in identifying accident location, and differences in accident cost reporting thresholds among agencies.

- It is overly sensitive to locations with very low volumes and one or more accidents. Rate is a ratio of accidents to traffic exposures, which implies a linear relation. This relation is not correct.

- It is not sensitive to accident severity.

- Comparison among rates (via ranking) is subject to error due to greater uncertainty (higher variability) for lower traffic exposures.

C. Frequency-Rate Method. This method is used to identify locations with both high accident frequencies and high accident rates. In application, the locations are ranked according to accident frequency and accident rate; those locations found at the higher levels of both lists are selected for treatment. Emphasis can be given to accident frequency by ranking it first and selecting from this ranking the locations with higher rates. Emphasis can be given to accident rate by reversing the order of ranking and selection. The exposure measures used include: (1) length of roadway segment, (2) time span for the accident frequency summary, and (3) traffic demand. The advantages of the method are:

- It mitigates the accident frequency method's tendency to be insensitive low-volume locations.

- It mitigates the accident rate method's tendency to be overly sensitive to low-volume locations.

However, its disadvantages include:

- It may not be the best predictor of hazard (in terms of reliability) due to large variability in accident data and changes in drivers, demand, and geometrics.

- Its accuracy is limited by under-reporting, errors in entering accident report data to the database, difficulty in identifying accident location, and differences in accident cost reporting thresholds among agencies.

- It is not sensitive to accident severity.

- Comparison among frequencies (via ranking) is subject to error due to greater uncertainty (higher variability) for higher frequencies.

- Comparison among rates (via ranking) is subject to error due to greater uncertainty (higher variability) for lower traffic exposures.

D. Rate-Quality Control Method. This method compares the accident rate for a spot location to the expected accident rate for similar locations with identical traffic exposures. The expected accident rate which must be exceeded for a location to be identified as critical is:

$$R_i = R_a + K\sqrt{\frac{R_a}{M_i} + \frac{1}{2M_i}} \qquad \textbf{(1)}$$

where,

R_i = expected accident rate for location *i* (accidents/year/million vehicle miles);
R_a = expected accident rate for all similar locations, (accidents/year/million vehicle miles);
M_i = annual traffic flow through location *i* (million vehicle miles/year); and
K = standard normal variable (one-tail test: K = 1.645 at 95% level of confidence).

The exposure measures used include: (1) length of roadway segment; (2) time span for the accident frequency summary: and (3) traffic demand. The advantage of this method is:

- It mitigates the accident rate method's tendency to make errors when comparing the rates of locations with differing traffic exposures. This method recognizes the higher variability associated with the rates of locations with lower traffic exposures.

The method's disadvantages include:

- It may not be the best predictor of hazard (in terms of reliability) due to large variability in accident data and changes in drivers, demand, and geometrics.

- Its accuracy is limited by under-reporting, errors in entering accident report data to the database, difficulty in identifying accident location, and differences in accident cost reporting thresholds among agencies.

- It is overly sensitive to locations with very low volumes and one or more accidents. The rate is a ratio of accidents to traffic exposures, implying a linear relation, which is not correct.

- It is not sensitive to accident severity.

E. Accident Severity Method. This method ranks a location's relative safety in terms of the number of accidents and the severity of these accidents. Severity is important because it correlates with the degree of suffering and magnitude of the lost time or lives experienced by the involved parties. The motivation behind this method is the assumption that locations with a high number of injuries are less "safe" than locations with more frequent property-damage-only (PDO) accidents.

Many different schemes are being used which fall in this category. One scheme is to weight the number of fatalities, injuries, and PDO accidents at all locations and then add them to get the Equivalent Property Damage Only (EPDO) rating. Locations with higher EPDO's would be deemed "hazardous." The EPDO from this scheme is highly correlated with accident frequency and has many of the same weaknesses as the Accident Frequency Method. A second scheme is to divide a location's EPDO by its traffic exposure to yield an EPDO rate. This scheme has many of the weaknesses of the Accident Rate Method. A third variation of this scheme is to combine a location's EPDO with its accident rate by addition or multiplication.

The exposure measures used include: (1) length of roadway segment; (2) time span for the accident frequency summary; and (3) traffic demand. The primary advantage of the method is:

- It includes severity as a measure of hazard.

Its disadvantages include:

- It may not be the best predictor of hazard (in terms of reliability) due to large variability in accident data and changes in drivers, demand, and geometrics.

- Its accuracy is limited by under-reporting, errors in entering accident report data to the database, difficulty in identifying accident location, and differences in accident cost reporting thresholds among agencies.

- It is overly sensitive to locations with very low volumes and one or more accidents. The rate is a ratio of accidents to traffic exposures, implying a linear relation, which is not correct.

- Variability in fatalities is very high and, when given large weight tin the EPDO calculation, will cause the location identification procedure to become unstable. Treatment programs will be unstable and locations highly scattered.

- The severity of an accident is highly dependent on non-location-related factors (e.g., seat-belt usage, vehicle types involved, number of occupants, occupant age, etc.).

- If the EPDO and accident rate are combined, it is possible that locations with a high PDO accident frequency will receive treatment.

F. Relative Severity Index. This method improves on the accident severity method above by computing a relative severity index. This method was developed by the Nebraska Department of Roads *(2)*. The units of the index are dollars. The interpretation of the index is expected cost of an accident at a given location. The index is calculated for each location as:

$$RSI = \frac{\sum T_i C_i}{\sum T_i} \tag{2}$$

where,
RSI= average relative severity index (dollars);
T_i = accident type *i* (e.g., rural multi-vehicle entering-at-angle); and
C_i = cost for accident type *i* (dollars).

The exposure measures used are: (1) length of roadway segment, (2) time span for the accident frequency summary, and (3) traffic demand. The advantages of this method are:

- It includes severity as a measure of hazard.

- It removes the variability in fatality and injury rates at individual locations and thereby makes the identification of hazardous locations more reliable.

- The RSI does not represent a frequency or a rate. Thus, it is not subject to the uncertainty (due to different variability) among locations with different traffic exposures that is associated with frequencies and rates.

The disadvantages of the RSI are:

- It may not be the best predictor of hazard (in terms of reliability) due to large variability in accident data and changes in drivers, demand, and geometrics.

- Its accuracy is limited by under-reporting, errors in entering accident report data to the database, difficulty in identifying accident location, and differences in accident cost reporting thresholds among agencies.

- If the RSI and accident rate (or frequency) are combined, it is possible that locations with a high PDO accident frequency will receive treatment.

- The RSI does not, by itself, measure accident potential. It only indicates relative severity if an accident should occur.

G. Non-Accident-Based Measures. This method incorporates the measurement of one or more geometric or operational characteristics of a given location. The characteristics measured are assumed to be correlated with accident potential or severity (although in most cases the correlation is based on intuition rather than empirical evidence).

The most recent research on surrogate measures of accident potential and severity is that performed by Perkins and Thompson *(3)*. Based on their research, the measures listed in Table 1 were found to offer the best compromise in terms of: (1) relationship to accidents, (2) clarity of definition, (3) credibility, (4) ease of data collection, and (5) affectability (*i.e.*, the likelihood that an improvement in the surrogate will result in an improvement in accident experience). In Table 1, speed reduction efficiency is defined as the ratio of the difference in actual speed reduction (average approach speed minus average speed at the curve midpoint) to the desired speed reduction (average approach speed minus the maximum permissible speed of the curve based on the friction factor). The advantages of surrogate measures are:

Table 1. Selected surrogates by highway situation and type of highway safety analysis. *(3)*

	Application in Highway Safety		
Highway Situation	Identification of Hazardous Locations	Evaluation of Countermeasures	Design Plan Review
Urban undivided tangent section	Access points/mile, turning volumes, speed changes/mile, fixed objects/mile	Speed changes/mile	Access points/mile, projected turning volumes
Rural undivided winding section	Curves/mile, lane width and shoulder width, physical evidence of driver error, speed changes/mile	Physical evidence of driver error, speed changes/mile	Curves/mile, lane width and shoulder width
Rural isolated curve	Speed reduction efficiency; curvature, grade, and distance since last curve; physical evidence of driver error; erratic maneuvers	Speed reduction efficiency, physical evidence of driver error, erratic maneuvers	Design speed differential; curvature, grade, and distance since last curve
Lane-drop location	Erratic maneuvers, merge gap availability, taper length, posted speed and sight distance	Erratic maneuvers, merge gap availability	Taper length, posted speed and sight distance
Narrow bridge	Ratio of bridge deck to pavement width, traffic mix, sight distance (time), physical evidence of driver error	Sight distance (time), physical evidence of driver error	Ratio of bridge deck to pavement width, traffic mix
Exit gore area	Deceleration lane length, sight distance, erratic maneuvers	Erratic maneuvers	Deceleration lane length, sight distance
Urban nonsignalized intersection	Traffic volume, approach speed and sight distance, traffic conflicts	Approach speed and sight distance, traffic conflicts	Projected traffic volume
Rural nonsignalized intersection	Traffic volume, approach speed and sight distance, traffic conflicts	Approach speed and sight distance, traffic conflicts	Projected traffic volume
Rural undivided tangent section	Access points/mile, speed changes/mile, lane width, physical evidence of driver error	Speed changes/mile, physical evidence of driver error	Access points/mile, lane width
Rural signalized intersection	Traffic conflicts, traffic volume, sight distance, delay	Traffic conflicts, delay	Projected traffic volume, sight distance

- They can be used to estimate accident potential when exposure is small (e.g., low traffic volume, short time span, short section length).

- They can be measured in a shorter time span than accidents because they occur more frequently than accidents.

The disadvantages of surrogate measures are:

- They are usually observed or measured over short time periods (*i.e.*, days) as opposed to years for accident-based measures. Thus, they may suffer from sampling error or temporal changes.

- They are neither direct measures of accident potential nor severity.

- Some measures are applicable only to some location types (*e.g.*, access points per mile is not applicable to intersections). Thus, it is difficult to compare or rank the relative hazard among different location types.

- Statistical relations with accident frequency have not been developed for many of the surrogate measures. Some measures (*e.g.*, conflicts and erratic maneuvers) have been found to have rather weak relationships to accidents.

An earlier version of this approach was developed by Taylor and Thompson *(1)*. This earlier version contained surrogate measures which were quantifiable among all location types (*e.g.*, rural two-lane intersections, urban multi-lane roadways). This version also describes a procedure for relating the magnitude of a measure to its "relative" hazard and then combining these indicators into a weighted hazard index for comparative or ranking purposes. The factors considered by Taylor and Thompson include:

- accident-based factors (accident frequency, accident rate, and accident severity);

- objective surrogate factors (V/C ratio, sight distance, traffic conflicts, and erratic maneuvers); and

- subjective surrogate factors (driver expectancy and information system deficiencies)

H. Empirical-Bayesian Methods. Methods in this category recognize that a current accident count is not the best means of estimating a location's true accident potential. These methods combine information about other "similar" locations with the accident count at each location in estimating the true accident potential. The combination procedure takes the form of a weighted mean of the location's accident count and that of the similar locations. The weights used represent the relative exposure of the location and the similar locations.

Higle and Witkowski *(4)* have described a methodology based on accident rates (*i.e.*, the measures of exposure are total traffic volume during the time period). Pendleton and Morris *(5)* have described a more general form wherein the units of exposure (length, time, traffic, *etc.*) are determined by the analyst. The two methods differ also in the method used to estimate the model parameters. Higle and Witkowski use the method of moments whereas Pendleton and Morris use a maximum likelihood approach which they have automated via a computer software program.

Pendleton and Morris caution users of their method who apply it to locations with low exposure levels. In these situations, the variability of the predicted true rate can be quite high. In both the Higle-and-Witkowski and Pendleton-and-Morris methods, the accident count is divided by all exposure measures. This approach implies a linear relationship between exposure and accident frequency. This implication is probably true for time exposure but, Hauer and others *(6)* have shown that it is not true for demands. It is not likely true for segment length. Hauer has approached this problem by restricting exposure to time. He uses a multivariate regression approach to avoid the need for "similar" locations, to minimize the data needed (by not requiring multiple locations for each traffic exposure), and to combine logical model formulations with existing data which enable the prediction of accident frequency at locations which are not commonly found (*e.g.*, locations with low exposures). Hauer's method uses the calibrated regression model to predict model parameters (it is equivalent to the method of moments). Pendleton and Morris argue that this approach is inferior to maximum likelihood estimation. On the other hand, Hauer's approach appears to be more efficient for hazardous location identification in the context of low traffic exposures because it is probably better able to yield a good estimate of the true rate. By regressing accident count over a range of exposures (given a sound model form), data for the full range of traffic demands, Hauer is able to make better use of available data and achieve a stronger model. The Pendleton and Morris model requires the subset of the data base into only those locations which have similar demands.

These methods are essentially improved statistical procedures for estimating the true accident count or accident rate for a location. They can also be used to estimate the true injury count or rate and to improve any of the preceding methods that require accident counts, accident rates, or severity information. They can also be used to determine the distribution of counts and rates. The distribution could then be used in a manner similar to the Rate-Quality Control method (which is based on a weak assumption of a normal distribution of accident counts) wherein a confidence interval is associated with each location's accident count or rate. Those locations exceeding the estimated true rate for all similar locations with a 90 or 95 percent level of confidence would be identified as hazardous.

Issues Pertinent to Low-Volume Rural Roadways

Accident potential (or risk) and accident severity are the desired measures of relative safety. Accident-based measures are the most direct measurement of accident potential and severity. However, due to the large variability in accident frequency, the use of accident-based measures is subject to gross errors or oversights (*i.e.*, false positives and false negatives). It is difficult to measure accident potential and severity at locations with low traffic exposure. This difficulty stems from low event occurrence and high variability in the corresponding accident rate. Identification methods which combine other measures with accident-based measures appear to offer the best means of identifying locations that are truly hazardous. The cost of obtaining the "other measures" must be considered when making the decision to use a combined method.

Hazardous locations on rural roads may be difficult to identify. A system-wide approach may make it easier to identify hazardous design elements, and the wholesale mitigation of these hazards may be more cost-effective. Identification methods using a location's past accident data as an estimate of its true accident potential may be subject to large errors unless empirical-Bayes methods are used. Of the empirical-Bayes methods discussed, the method developed by Hauer *(6)* appears to offer the better means of estimating the accident potential (and/or severity) of locations, particularly those with low exposures.

EVALUATION METHODOLOGIES

Overview

After a highway safety improvement is installed, it must be evaluated in order to determine its level of performance for future use. There are several evaluation processes, and depending on which evaluation method is used, a different conclusion about the worthiness of the improvement may be reached.

When evaluating improvements to be placed on low-volume roadways, concern must be given as to whether the method is appropriate. If the evaluation criteria is reduction in number of accidents, the erratic, infrequent occurrences of accidents on low-volume roads may result in a misleading conclusion. Most states use a variation of the benefit-cost method, where each alternative is given a benefit-cost ratio:

$$\frac{B}{C} = \frac{\textit{Annual Benefits (cost of accidents prevented)}}{\textit{Amortized Cost of Improvement and Maintenance}}$$

The alternatives are then ranked with the highest B/C ratio receiving highest priority. Similarly, a cost-effectiveness ratio has been developed by the state of Washington *(7)*, which compares cost to relative hazard reduction:

$$\textit{cost-effectiveness} = \frac{C_I + (Cm_A - Cm_B) + (P_{HA} C_{HA} - P_{HB} C_{HB})}{H_B - H_A}$$

where,
C_I = annualized first cost of improvement;
Cm_B= annual cost of maintenance for existing obstacle;
Cm_A= annual cost of maintenance for improved obstacle;
P_{HB} = probability of striking existing obstacle;
P_{HA} = probability of striking improved obstacle;
C_{HB} = annual repair cost for obstacle before improvement;
C_{HA} = annual repair cost for obstacle after improvement;
H_A = hazard index after improvement; and
H_B = hazard index before improvement.

The hazard index is:

$$H = V \cdot P(E) \cdot P(C/E) \cdot P(I/C)$$

where,
V = number of vehicles per year passing by obstacle;
P(E) = probability of vehicle encroachment on roadside;
P(C/E) = probability of a collision with obstacle given that encroachment has occurred; and
P(I/C) = probability of injury given that a collision has occurred.

Another cost-effectiveness method used in Oakland County, Michigan *(8)* assigns scores for reduction of accident frequency, accident rate, and severity rate. Multipliers for high, medium, and low accident frequency adjust the three scores, and the sum is divided by the cost of the project and multiplied by 1,000,000 for a cost-effectiveness score. Then other factors are considered, such as operations improvements, social and economic impacts, and maintenance and service improvements. Unlike the benefit-cost ratio, the cost-effectiveness method does not require an assigned monetary value to accidents saved. A study conducted in Indiana *(7)* rated cost-effectiveness better than benefit-cost for its ability to incorporate these nonpriceable effects.

However, the approach of choosing the most cost-effective solution for each location may not always result in the best combination of solutions over the network. An integer programming algorithm *(10)* has been developed that, with the help of a computer, will maximize the total benefit of the system while acting under a resource constraint.

Still, no matter which method is used, the main criterion is the comparison between the accident costs saved and the cost of the improvement. If an average value of accident costs is used, low-volume road projects will almost always have lower priorities than those on higher volume roadways, because the number of occurrences will be much greater. However, two changes can help increase the priorities of projects on low-volume roadways:

1. **The reduction in accident costs must include provisions for different types of accidents prevented as well as degrees of severity.** Most state agencies have accident reduction figures for improvements, which predict percent reduction of each type of accident (head-on, right angle, sideswipe, *etc.*). For each of these types, reduction of PDO, injury, and fatality accidents should be calculated. Because accidents on low-volume roads tend to be more severe (*i.e.*, involving injuries and fatalities) the accident costs can be more accurately represented than by an average accident value. This will tend to make low-volume road projects more cost-effective. Also, it must be noted that some experts feel that current values of fatality costs are too low. Therefore, if the costs of fatalities were higher, the cost-effectiveness of projects on low-volume rural roads would also be increased.

2. **Less expensive safety improvements should be considered.** If the denominator of the cost-effectiveness ratio is cost, the low-volume road project must be relatively inexpensive in order to compete with major highway projects. Unfortunately, less costly usually means less effective. Under the crash testing guidelines of NCHRP 230 *(11)*, the same FHWA standards applied to both low-volume roads and interstate highways. This meant that only the more expensive high-standard devices (guardrails, attenuators, etc.) could be installed, and rarely will these devices be cost-effective on low-volume roads. Recently, new guidelines have been published in NCHRP 350 *(12)*, which allow for a new test category which includes most low-volume roads. These devices must satisfy a 70 km/h crash, as opposed to 100 km/h, as called

for under the previous standards. This may open up a new market for devices designed for low-volume roads.

Methodologies

There are four general types of evaluation methodologies. In order of increasing subjectivity, they are naturalistic studies, artificial studies, systems models, and subjective assessment.

A. Naturalistic Studies. These studies include in-the-field observation of performance. In a true experimental design, random installation sites are selected, and results are compared with a control group. This is the most empirical methodology; unfortunately, most agencies cannot spare the time or funding for such large-scale experiments. Instead, a quasi-experimental design, the before-after study, is used. While the results obtained from a before-after study may appear to be very conclusive, other factors, such as regression to the mean (r-t-m), may play a larger role. For example, a site may be chosen for a improvement because of an abnormally high accident rate. After the improvement is installed, a modest decline in accidents is observed. Is the decline due to the improvement, or is the accident rate just returning to normal levels? In order to guard against regression-to-the-mean, a large sample size must be obtained.

B. Artificial Studies. These studies are conducted under a controlled setting, such as a laboratory or a crash testing facility. There are two types of artificial studies. Physical performance tests measure the quantitative effects of the device on the vehicle; these include crash testing performed under FHWA standards. Behavior performance tests study the reaction of the driver to the driver; these include driving simulators testing new signs. Artificial studies can be very helpful in determining the utility of a device, but the controlled environment is only an approximation of real installation.

C. Systems Models. These models attempt to predict the occurrence and severity of accidents based on the characteristics of the roadway. With the additional input of a safety device, reduction in accident rate and degree can be predicted. However, the predictions are often based on assumptions that have not been scientifically verified.

D. Subjective Assessment. This is what engineers must rely on when none of the above is available, also called "engineering judgment". Using intuition and past experience, the engineer speculates on the effectiveness of the device. Subjective assessment can be accident specific, where the details of a type of accident are reviewed to determine the effects of a countermeasure; location specific, when a certain setting has several proposed countermeasures from which to choose; or countermeasure specific, where a single countermeasure is studied to determine its potential accident reduction for all cases.

Measures of Effectiveness

A. Accident Rate. With the database capabilities now available, states can have comprehensive accident records which can be used for naturalistic studies. If a countermeasure is to be studied, the collection of "before installation" data will not be as difficult and time-consuming with the aid of a computerized record system. However, for low-volume roads, to gather enough "after installation" data for a significant conclusion may take years.

B. Accident Surrogates. In some cases, non-accident variables can be used to predict accidents. For example, on rural isolated curves, it was shown that the outside-lane accident rate could be related to the distance to last event and the speed differential of traffic. If relationships such as these can be proven significant, they are useful tools in assigning a hazard index. However, different relationships will exist for different environments, so care must be used in selecting surrogates developed in another state. It may be advisable for a state to develop its own surrogates, but this would require extensive studies.

APPROACH TO SAFETY IMPROVEMENTS

System-wide vs. Elemental

Strate *(13)* writes: "Safety programs that stress the need for systematic analysis generally reap a higher rate of return than those that do not." There are several advantages afforded by a system-wide approach to safety over a case-by-case philosophy, but they may not be readily apparent.

- A system-wide approach improves consistency, whereas spot safety improvements do not necessarily. Roadway consistency encompasses driver expectancy, as well as the "forgiving roadside" concept. Low-volume roads frequently lack consistency, as needs are addressed in a piecemeal fashion.

- A system-wide approach affects a broad area, rather than the small part of a jurisdiction affected by a spot improvement. Because there are many miles of low-volume roads, spot improvements neglect much of the system.

- A system-wide approach includes multiple projects as a group, while spot improvements are handled individually. Instead of designing and contracting several projects, they can be conglomerated, saving time and administrative costs.

There are three general types of system-wide safety improvements:

1. System-wide for one element only, such as guardrail retrofitting

2. Safety features included in construction, implemented through design standards

3. Treatment of side effects, so that accidents do not "migrate"

Types 1 and 2 are the most pertinent to low-volume rural roadways. Ivey *(14)* mentions several low-cost improvements, each of which, if applied in a system-wide manner, could be cost effective, such as headwall removal, which would not be economically feasible on an individual basis. For example, 3R projects present opportunities for the safety features mentioned in type 2. They can be an effective means for implementing safety consistency. However, 3R design practices vary widely among agencies. The 3R projects are initiated primarily to address pavement repair and rehabilitation needs. Federal-aid 3R projects frequently widen lanes and shoulders, but seldom reconstruct sharp curves or narrow bridge decks. Not enough is known about the safety effects of such improvements.

A safety-conscious design process is needed for 3R projects. This process should include the following steps:

1. Assessment of current conditions, including a field review.

2. Determination of project scope.

3. Documentation of the design process.

4. Review of the design with traffic and safety specialists.

Elements to be considered during the 3R design process include:

- accident history

- guardrail presence

- structural adequacy of bridge railings

- positive guidance (signing and marking of hazards such as no-passing zones, narrow bridges, and curves)

- horizontal and vertical alignment

Simple improvements are often overlooked in 3R projects. Listed below are a few examples:

- Improving roadside traversability through slope flattening, ditch regrading and relocation, or removal of unnecessary guardrail.

- Removing or shielding roadside obstacles such as sign supports, utility poles, and rigid mailbox supports.

- Replacing obsolete guardrail and bridge rail systems.

- Cutting trees and brush to restore adequate sight distance.

- Installing new or upgraded signing and pavement markings.

Functional categories should be developed for the state highway system, in order to improve consistency with driver expectancy. Washington State DOT *(15)* uses three functional categories:

1. Interstate routes, principal arterials: Design standards apply.

2. Minor arterials: 3R standards apply.

3. Local roads: Structural integrity and operational safety maintained.

Hazard Elimination vs. Resurfacing, Restoration and Rehabilitation

The safety concerns of low-volume rural roads cannot be addressed by hazard elimination projects alone. Hazard elimination programs are assembled using cost-effectiveness criteria, and low-volume locations rarely can meet these criteria. The most thorough safety policy for low-volume road needs is a system-wide approach, incorporated through resurfacing, restoration, and rehabilitation (3R) projects. Hazard elimination programs only address locations with accident history, not accident potential. A hazard must "make its presence known" before receiving attention in the form of a countermeasure. The point has frequently been made that because low-volume roads have less exposure, hazards may go undetected for lack of accidents. However, if a safety review is included as part of the 3R design process, hazards can be discovered before accident history develops.

Even if a low-volume hazard has sufficient accident history to be included in the state's high-hazard list, the countermeasures proposed may not be justifiable from a cost-effectiveness standpoint. The hazard therefore fails to be included in the safety improvement program, and in most cases, no action is taken. Lower-cost countermeasures can be proposed for hazards found in 3R design, those types too large to be performed by maintenance crews but not large enough to comprise individual projects. These are more easily cost-justified, especially if economies of scale can be achieved from many installations on a single 3R project.

For example, a 5-mile section of road includes three sharp (10 degree) curves, each 1 mile apart. The road has 10-foot lanes with 2-foot earth shoulders, and the roadside barrier is substandard cable. The volume is 800 ADT, and in the past year fifteen accidents occurred at the west curve, none at the middle curve, and four accidents at the east curve. The westernmost curve experienced enough accidents to be classified as high-hazard, but the other two curves did not. Realignment was not proposed for the westernmost curve because that is very cost-prohibitive. Instead, the lanes are to be widened to 12 feet, the shoulders widened to 6 feet, and W-beam guardrail is to be installed. These improvements rate a benefit-cost ratio of 1.1, but in some states there are many other improvement candidates with higher ratios than this, so this project may never be programmed. Even if it were implemented, the phenomenon known as "accident migration" will likely occur. The western curve has been upgraded, and less demand is made of the driver to negotiate the curve. However, the middle curve, which is identical to the pre-improvement western curve, still requires a high maneuvering ability. In addition, the driver's expectancy may be lowered by improvements to the western curve (*i.e.*, an eastbound driver, after passing the first curve, with its 12-foot lanes and 6-foot shoulders, would most likely expect the same conditions for the middle curve). Some of the accidents at the western curve would be displaced to the middle curve, and additional accidents may occur there due to the violation of driver expectancy.

If this same 5-mile section were due for 3R work, and if safety concerns are incorporated into the design process, the deficiencies of the entire section would be considered. The narrow lanes and shoulders would be found in conflict with 3R design standards, and widening action would be taken for all three curves, if not the entire section. The guardrail would likely be implemented also. No accident migration will occur (assuming that no substandard curves exist on either side of the section), driver expectancy would not be violated, and some cost savings would be realized by correcting all three curves in one project, as opposed to three separate projects. Thus, the safety concerns of low-volume roads should not be addressed by hazard-elimination alone. Safety review must also be incorporated into resurfacing projects, and 3R standards provide an appropriate vehicle.

Chapter 3

SURVEY OF STATE HIGHWAY SAFETY IMPROVEMENT PROGRAMS

The four states (*i.e.*, Iowa, Kansas, Missouri, and Nebraska) in the Midwest Region were surveyed to obtain information about their highway safety improvement programs and issues pertinent to traffic safety on low-volume rural roadways. Based on this information and the literature review presented in Chapter 2, modifications to existing policies for more effectively incorporating the needs of low-volume rural roadways were developed. The procedure and results of the survey are presented in this chapter.

PROCEDURE

Telephone interviews were conducted with individuals involved in the highway safety improvement programs in each state. This survey method was used to clarify any uncertainty related to the questions and to increase the amount and timeliness of the responses.

The interview questions, listed in Table 2, covered four subject categories:

- Hazardous Location Identification
- Countermeasure Evaluation
- System-wide Safety Improvements
- Safety Program Planning

The interview responses were transcribed and paraphrased for concision. These transcripts were then returned to the respective state for verification, and follow-up telephone contacts were made with the correspondents to clarify any discrepancies or misinterpretation found in the transcripts. The compiled transcripts can be found in the appendix. The results below are a summary of those responses.

Table 2. Survey questions.

Hazardous Location Identification

1. How are hazardous locations identified, and what measure is used (accident frequency, accident rate, frequency-rate, rate-quality, severity. relative severity, non-accident measures, surrogates, other)?
2. Is a hazard index used in the identification process?
3. Do you feel that the method adequately identifies hazardous locations on low-volume roads? Are any special procedures used to identify low-volume-roadway hazards?

Countermeasure Evaluation

1. How are countermeasures selected for implementation (B/C, cost-effectiveness, other)?
2. What post-implementation studies are done? What is the measure of effectiveness (accidents, accident rate, cost of accidents, non-accident measures, reduction in hazard index, other)?
3. Where are accident cost figures taken from (FHWA, NSC, other)?
4. What accident reduction factors are used?

System-wide Safety Improvements

1. Are system-wide safety improvements considered and implemented?
2. Are any low-cost, light-duty countermeasures considered for low-volume locations?
3. Are safety improvements incorporated into 3R projects?

Safety Program Planning

1. How is the safety program administered (*e.g.*, safety committee)? How often are meetings? How often is programming done (annually, quarterly, monthly)?
2. Are dynamic programming algorithms used in planning projects?
3. What role does public input play in the planning process?
4. Are enough projects programmed to keep pace with federal safety funding?
5. Do you feel that programming procedures adequately accommodate low-volume hazardous locations?

RESULTS

Hazardous Location Identification

- A form of accident rate is compared to a critical rate in each state to rank candidates for safety improvement projects, however, one state equally weights total accidents, accident rate, and value-loss for each candidate. Two of the states consider intersections and controlled-access sections separately. Categorization by type of facility was made in two of the states. Two states use accident data from the past five years, one uses data from the past three years, and one uses data from the past two years. Three of the correspondents mentioned input from local agencies as a means of identifying hazardous locations.

- None of the states use a hazard index to identify hazardous locations. One state is developing a new system which will assign expected values of accident rates to physical feature in the roadway.

- Each correspondent had concerns about the ability of his state's HSIP to identify low-volume hazardous locations. Some weaknesses mentioned were urban locations overshadowing rural locations, and intersections being compared with access-controlled sections.

Countermeasure Evaluation

- Benefit/cost ratios are used to select countermeasures in all four states. Two states normally require a B/C ratio greater than 1.0 for justification of a project. One state requires a 1.1 B/C ratio for HES projects, and a 1.5 B/C ratio for the state's portion of the funding on Traffic Safety Improvement Projects.

- Two states use FHWA's 1991 accident cost figures, one state uses FHWA's 1988 cost figures, and one state developed its own cost figures.

- For rating the effectiveness of safety appurtenances, one state has developed a database using accident reduction factors from past projects, updated yearly. Two states have accident reduction tables compiled from other sources, and one state uses a combination of in-house figures and those obtained from other studies.

System-wide Safety Improvements

- System-wide safety improvement projects are not performed for anything other than signs and guardrail. One state is considering district-wide guardrail and raised pavement marker projects.

- All four states have a hierarchy of improvements ranked by cost. Among the "low-end" countermeasures mentioned were larger stop signs, widening pavement edge lines, and attaching guardrail to bridge railing.

- Two of the four states use 3R projects extensively as a means for incorporating safety improvements by having 3R design standards that call for safety inspections.

Safety Program Planning

- The four states have diverse structures for planning safety projects. One state has a safety committee which meets monthly. In two states, a division within the state office selects projects and presents them to the state planning authority on an annual basis. The traffic engineering bureau selects projects every two years in the other state.

- None of the states use any dynamic programming algorithms for projects which optimize the use of funds over the system, but no problems in keeping pace with federal safety funds were reported.

- Two states have regular public information meetings in each district in order to receive feedback, while local agencies recommend locations in the other two states.

Chapter 4

CONCLUSIONS

Hazards on low-volume rural roadways present unique challenges to safety engineers. Because accident history is the most common criterion, the low exposure rate of rural roads implies that hazards will be more difficult to identify than on higher-volume facilities. If the hazard is identified, then a countermeasure must be cost-justified before any action is taken. The hazard will usually remain unabated after improvements fail to clear these two hurdles, which are present in the safety policies of each of the four states of Region VII.

Hazardous Location Identification

Identification methods which combine other measures with accident-based measures appear to offer the best means of identifying locations that are truly hazardous. Currently, the four states use a form of accident rate which is compared to a critical rate for the type of facility. Methods using a location's accident history as an estimate of its true accident potential, as the four states do, may be subject to large errors unless an empirical-Bayes method is used, such as the one developed by Hauer. Two of the states use five years of accident data; this is recommended for the other two states because the larger the database, the more accurate the description of hazard, especially in low-volume locations. Three of the correspondents mentioned input from local agencies as a means of identifying hazardous locations.

A system-wide survey using a hazard index would be the most effective method for low-volume locations, because it eliminates dependency on accident history. However, the initial documentation effort would be formidable. Until the states have the opportunity to undertake this effort, accident rate (modified by empirical-Bayes methods) is the next best identification method.

Countermeasure Evaluation

Benefit/cost ratios are used to select countermeasures in all four states. A cost-effectiveness approach might be more conducive to low-volume locations if the criterion used is dollars per life saved, since the value of life tends to be underestimated for purposes of benefit-cost analysis. For rating the effectiveness of safety appurtenances, one state has developed a database using accident reduction factors from past projects, updated yearly. Two states have accident reduction tables compiled from other sources, and one state uses a combination of in-house figures and those obtained from other studies. While the database for each state may be limited by small sample sizes for certain improvements, it is important that each state attempt to keep its own records because of conditions unique to the state. However, the feasibility of combining the records of the four states into one regional database should be investigated.

System-wide Safety Improvements

Highway Safety Improvement Programs will not accommodate every hazardous situation on low-volume rural roadways. A system-wide approach will better meet the needs of these roadways. Economies of scale can be achieved, and if a "hazard inventory" is conducted, comprehensive improvements can be made instead of the piecemeal, project-by-project approach. One of the best ways to apply a system-wide approach is to include safety inventories in the 3R process, which two of the states have done. If safety design standards are adopted for the 3R process, then the hazards can be addressed each time the road is resurfaced. These standards can be lower than those for new construction, yet still afford improvement over the archaic status of many older low-volume rural roadways.

While lower-cost improvements in the areas of signage and striping have been investigated by the states, efforts should be expanded to include safety appurtenances for locations which require attention but do not have the exposure to merit heavy-duty appurtenances.

Safety Program Planning

It was learned through the survey that the four states have various planning mechanisms for safety projects. None of them, however, include a computer algorithm for optimizing the benefits over the entire system. While engineering judgment and human factors should play a role in choosing projects, it should be noted that choosing projects with the best B/C ratios may not always result in the optimal use of hazard reduction funds for the entire system. The public should still be involved in the recommendation process, and public information meetings held regularly in two states are an excellent means of obtaining citizen input.

Chapter 5

RECOMMENDATIONS

After reviewing the states' policies, the knowledge gained from the literature was applied in order to develop recommendations with respect to modifications to their highway safety improvement program policies. Also, aspects of a model policy were compiled, which might be incorporated into a safety management system as required by FHWA.

HAZARD IDENTIFICATION

An Empirical-Bayesian method should be used for identifying hazardous locations, with locations divided into and rated by categories, such as intersection or link, rural or urban, number of lanes, and degree of access control. In addition, a hazard inventory should be made of the entire state highway system, resulting in the assignment of hazard indices to every location. A combination of these two resources would be used in the programming of safety projects.

The rural/urban categorization would afford a better opportunity of identifying hazards on low-volume rural roadways apart from high-volume urban locations. The inclusion of accident severity also would favor rural locations, as rural accidents tend to be more severe. The hazard index would provide a non-accident-based measure for prioritizing low-volume rural locations which have little accident experience.

Although accident history is the most direct measurement of accident potential and severity, previous research cited in the literature review has found it to be unreliable as a predictor on rural roadways with low traffic exposure. A Bayesian method should be used to modify the accident rate for a location. This would be well complemented by non-accident based measures in the form of hazard indices. An inventory of all roadway and roadside hazards should be made for all roads on the state highway system, either through maintenance crews or through a photolog search. A hazard index, computed as follows, would be used to rank the hazardous locations:

$$H = V \cdot P(E) \cdot P(C/E) \cdot P(I/C)$$

where,

V = number of vehicles per year passing by obstacle;
P(E) = probability of vehicle encroachment on roadside;
P(C/E) = probability of a collision with obstacle given that encroachment has occurred; and
P(I/C) = probability of injury given that a collision has occurred.

Computer programs are available to calculate this hazard index. Each district office would maintain an inventory for their area, correcting as many hazards as possible with agency resources, and submitting bids for other work as funds become available. Many hazards could be addressed during 3R projects.

COUNTERMEASURE EVALUATION

A comprehensive database including accident locations, accident severity, roadside hazards, and countermeasure performance should be used for evaluating and selecting countermeasures. New, lower-cost improvements should be investigated and considered for implementation. A hierarchy of improvements, from low-cost countermeasures to large-scale projects, could be developed from the database to aid in the selection process.

More definitive and accurate data on the effectiveness of countermeasures on low-volume roads are needed to take some of the guesswork out of the selection process. Pursuing low-cost improvements would be beneficial for low-volume rural roads, because these are more easily cost-justified.

It is vital to the success of any safety program that adequate records be made of safety projects. A three-year before-and-after study is required for every federal-aid safety project, but this is the extent of most states' records. Usually only accident rates are compared for the two periods, and only two states of the four states in the region maintain a database of countermeasure effectiveness and expected accident reduction. With present computer capabilities, each state should be able to maintain a comprehensive database that includes accident locations, accident severity, roadside hazards, and countermeasure performance.

With the aid of this database, a hierarchy of improvements could be constructed for use in countermeasure selection. The criterion for ranking could be cost effectiveness (*i.e.*, accident severity reduction per dollar of project cost). A systematic selection process could then be followed, with low cost improvements such as signs and striping considered first, followed by intermediate improvements such as appurtenances, and if deemed appropriate, major improvements such as realignment. This would also be conducive to computer application in compiling a safety program.

When selecting countermeasures, all four states currently use some form of benefit-cost ratio and consider each project separately. If a hazard index such as the one shown above is used, it would be possible to use a cost-effectiveness ratio, which compares the cost of the countermeasure to its degree of safety improvement. This method would more accurately incorporate the severity of a hazard, which is important because accidents on low-volume rural roadways tend to be more severe than those on other roadways.

If a safety program contains large numbers of potential improvements, it has been shown that choosing the most cost-effective solution for each location may not result in the best combination of solutions over the network. Again, a comprehensive computer database using an integer programming algorithm could be used to maximize the total benefit to the system.

Too often hazards on low-volume roads go unaddressed because the countermeasures proposed cannot be economically justified. Heavy-duty end treatments and guardrails are usually too costly to be implemented on low-volume rural roads. However, new crash testing standards have created a new category of low-cost appurtenances. A market may be developed for these products on low-volume roads; these lower-cost devices would be more easily justified.

SYSTEM-WIDE SAFETY IMPROVEMENTS

Opportunities to implement system-wide safety improvements should be investigated to the fullest extent, and safety officials need to realize the benefits of such campaigns. The 3R program is one vehicle for such improvements. Separate design standards should be approved for 3R projects, and a safety review should be incorporated into all projects, even resurfacing jobs.

System-wide safety programs represent the most effective means for addressing the safety needs of low-volume rural roadways. The 3R design standards for low-volume roadways, even if less stringent than those of high-volume roadways, would foster much-needed consistency.

According to the survey results presented in Chapter 3, past system-wide safety improvements, such as guardrail retrofitting, have proven to be cost-effective in all four states.

Often economies of scale can be achieved by undertaking system-wide programs as opposed to individual projects. Consistency throughout the system also improves driver expectancy with respect to signing and striping. Low-volume rural roadways often have breaks in consistency due to spot improvements, thereby compromising safety. System-wide improvements could be one of the most effective means for correcting deficiencies on low-volume rural roadways.

Another effective method for implementing safety improvements on low-volume rural roadways would be to incorporate them into resurfacing, restoration, and rehabilitation (3R) projects. As mentioned earlier, hazards on low-volume roads are rarely discovered by typical hazardous-location identification programs. Unless a hazard inventory is conducted by the agency, these hazards often go undetected. But, if a safety review is performed each time any improvement is planned, the hazards could at least be identified, and appropriate action could be incorporated into the project, be it resurfacing or otherwise.

To facilitate the safety review for 3R projects, 3R design standards should be developed which are distinct from the state's construction standards. This would facilitate the demonstration of the deficiencies of a road section. Also, it would make improvements more economical than building to new construction standards, which is required for federal 3R funding when a state does not have 3R standards. Otherwise, design exceptions must be approved by FHWA.

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APPENDIX

Survey Questions and Answers

A. Hazardous Location Identification

1. *How are hazardous locations identified, and what measure is used (accident frequency, accident rate, frequency-rate, rate-quality control, severity, relative severity, non-accident measures, surrogates, other)?*

Iowa	The state highway system in Iowa is divided into links and nodes based on the Township and Range system. Each link and node has an identification number, and this number is listed on each accident report. Five years of accident data is used to prepare the Safety Candidates List. Links and nodes are evaluated together in three categories: total accidents, accident rate, and value-loss. (The accident rate is accidents per million *entering* vehicles for both links and nodes.) Points are assigned to each link and node according to its rank in each category, and the cumulative points determine the location's rank on the Safety Candidates List. To be considered for Hazard Elimination Safety (HES) funds, a location must rank in the top 200 of the Safety Candidates List. Iowa Department of Transportation (IDOT) also has a Traffic Safety Improvement Program, supported by ½% of Iowa's road use tax fund, for which local jurisdictions submit project concepts to the Transportation Safety Bureau.
Kansas	The Kansas Department of Transportation (KDOT) uses a High-Frequency Accident Location Analysis System (HFALAS) in which the state highway system is examined yearly using a .3 mile window which moves by .1 mile increments. The past five years of accident data are used, and a critical rate (accidents/mvm) is calculated for several classifications of roadway (i.e. rural 2-lane, urban 4-lane undivided, etc.). Every two years, the top 50 or so locations are selected for review, and each city over 5000 population recommends 5 locations.
Missouri	The Missouri Highway and Transportation Department (MHTD) uses the High Hazard Program to identify locations. This program annually scans the state highway system by .1 mile increments with .05 mile overlap sections, with accidents per 100 million vehicle-miles of travel as the criterion traveled from the past three years is used in identification as well as calculating a critical rate for

three highway classes: U.S. routes, state routes, and "lettered" routes, which are county collector roads on the state system. Interstate routes are not included in the High Hazard Program. Missouri also has a wet pavement accident reduction program. The data from the High Hazard Program is divided into wet and dry accidents. Accident locations for any .1 mile sections of roadway having a wet/dry accident ratio greater than .25 and more than 20 accidents are listed by the computer. This listing includes the three most recent years and is sorted by decreasing C-factor. "C" represents the number of accidents expected to be prevented within a 3-year period if the W/D ratio is reduced to the norm. Thus, the listing is equivalent to decreasing potential improvement.

Nebraska The Nebraska Department of Roads (NDOR) uses the Rate Quality Control Method to identify hazardous locations on the state's highway system. The expected accident rate is calculated using 2 year accident data for intersections, clusters (spots where 3 or more accidents occur within a selected cluster length), and sections. All locations which exceed their respective rates are then ranked by severity. The top third of locations for each district are listed in the Safety Improvement Locations Book, which is published semi-annually. The top 30 intersections and clusters statewide and the top 10 locations of each type with the largest increases and decreases in accidents are listed as well. The safety committee also accepts input from cities, counties, law enforcement, and district office personnel when identifying hazardous locations. The safety committee then reviews accident histories at approximately four sites per month, using accident diagrams, photologs, and other data as required. Field reviews are not normally conducted.

2. *Is a hazard index used in the identification process?*

$HI = V\,[P(E)]\,[P(C/E)]\,[P(I/C)]$

where V = *Vehicles passing object per year*

$P(E)$ = *Probability of encroachment*

$P(C/E)$ = *Probability of collision given encroachments*

$P(I/C)$ = *Probability of injury given collision*

Iowa No hazard index is used for identification, but the computer program ROADSIDE does figure a similar index, plus a severity index for bridge designs to compute dollar loss figures for B/C analyses.

Kansas	A hazard index has not been incorporated into the identification process.
Missouri	No hazard index is used to identify locations at this time.
Nebraska	A hazard index has not been incorporated into the identification process.

3. *Do you feel that the method adequately identifies hazardous locations on low-volume roads? Are any special procedures used to identify low-volume-roadway hazards?*

Iowa	Because rural and urban locations are evaluated together, urban locations with higher exposures dominate the Total Accident and Value Loss categories. Low-volume roads could be more effectively treated if they were ranked separately.
Kansas	Yes and no. Some locations "fall through the cracks" of the identification process if the accident history is not outstanding.
Missouri	Because there is no separate process for identifying intersections, their inherent greater safety risk makes them more likely to appear on the high-hazard list than non-intersection locations. This makes it difficult to identify dangerous curves, bridges, etc. A new system is being developed which will assign expected values of accident rates to physical features in the roadway, such as those mentioned above.
Nebraska	Hazardous locations on low-volume roads may not be detected if no accidents are reported during the two-year period. A longer study period would more accurately reflect the degree of hazard. NDOR has enough candidates with significant accident history that searching for more candidates based on accident potential is unwarranted. If a hazardous location does not have significant accident history, it can still be identified by local agencies or the public.

B. Countermeasure Evaluation

1. *How are countermeasures selected for implementation (B/C, cost-effectiveness, other)?*

Iowa	Before selecting a countermeasure, officials usually conduct a field review. IDOT uses benefit-cost analysis to determine feasible countermeasures. A B/C ratio of 1.1 is usually required for a project using HES funds. For Traffic Safety Improvement Projects, a B/C ratio of 1.5 is usually necessary, but this is based on only the state's portion of the cost, i.e. the amount asked for by the local agency.
Kansas	KDOT uses benefit-cost analysis to determine feasible countermeasures for large improvements.
Missouri	MHTD uses benefit-cost analysis to determine feasible countermeasures. A B/C ratio of 1.0 or greater is required for project justification. Some problems are incurred when accident rates drop between project selection and the time of bidding.
Nebraska	NDOR uses benefit-cost analysis to determine feasible countermeasures. A B/C ratio of 1.0 is normally required for project justification.

2. *What post-implementation studies are done? What is the MOE (accidents, accident rate, cost of accidents, non-accident measures, reduction in hazard index, other)?*

Iowa	Every HES project is evaluated by a before-and-after study of total accidents by severity, accident rate, or pattern reduction. Data is taken from a 3 to 5 year period before and after the improvement.
Kansas	Accident numbers and rates are compared for the three-year period before and after the improvement on all federal-aid projects and whenever possible on state projects.
Missouri	Accident rates are compared for the three year period before and after the improvement.

Nebraska Accident rates are compared for the three-year period before and after the improvement. Economic analyses are then performed on improvements which prove statistically significant. Considerations are made for outside influences (changes in traffic makeup, other nearby safety improvements, etc.) when interpreting the results. Unfortunately, no database containing the results of the evaluations has been developed.

3. *Where are accident cost figures taken from (FHWA, NSC, other)?*

Iowa IDOT has devised their own cost figures, which are given in dollars per person:

Fatality	500,000
Type II injury	100,000
Type III	6,000
Type IV	1,500
PDO	1,000
Generalized Rural	22,000
Generalized Urban	13,000

The base figures were computed in April 1990, and are updated each year using the Iowa Consumer Price Index.

Kansas KDOT uses accident costs published in "The Costs of Highway Crashes", FHWA-RD-91-055, October 1991, updated using the Kansas Consumer Price Index.

Missouri MHTD uses accident costs published in FHWA Technical Advisory T 7570.1, "Motor Vehicle Accident Costs", June 30, 1988, adjusted for the consumer price index. A newer report, "The Costs of Highway Crashes", FHWA-RD-91-055, October 1991, provides newer figures which are substantially higher than those of T 7570.1. Because accidents on low-volume roads tend to be more severe, the new figures will improve the cost-effectiveness of their safety improvements.

Nebraska NDOR formerly used accident costs published in FHWA Technical Advisory T 7570.1, "Motor Vehicle Accident Costs", June 30, 1988. A newer report adopted by NDOR, "The Costs of Highway Crashes", FHWA-RD-91-055, October 1991, provides newer figures which are substantially higher than those of T 7570.1. Because accidents on low-volume roads tend to be more severe, the new figures will improve the cost-effectiveness of their safety improvements.

4. What accident reduction factors are used?

Iowa	IDOT uses severity reduction factors from its own past projects as well as from national studies. These severity reduction factors are derived from accident reduction factors using cost relationships between different types of accidents. Then the severity reduction factors may be applied directly to total accident cost data for each site, to obtain a benefit of accident cost savings due to the improvement. Generally, reduction factors larger than 40% are not used in the analysis. The severity reduction factor table was compiled in 1985; additions have been made, but the table has not been comprehensively updated.
Kansas	KDOT uses a database, updated annually, which includes accident reduction figures from past projects to estimate accident cost savings.
Missouri	In the compilation of MHTD's High Accident Location Manual (1990), results from many studies were included in an accident reduction factor table.
Nebraska	A number of resources are used for obtaining accident reduction figures: FHWA bulletins, technical journals, and results of previous NDOR projects, but neither a table of accident reduction figures nor a database of past NDOR results has been developed.

C. System-wide Safety Improvements

1. Are system-wide safety improvements considered and implemented?

Iowa	Bridge rail replacement has been undertaken on Iowa's interstate highways, and culvert headwall removal, utility corridor improvements, intersection lighting, and T-intersection signing are among routine improvements, but most retrofitting is done in 3R projects.
Kansas	The most recent examples would be no-passing pennants and chevron curve markers.
Missouri	Replacement of turndown guardrail end treatments and connections to bridge rails are some examples of system-wide safety improvements in Missouri.

Nebraska The safety committee has not programmed any system-wide projects in recent years, but district-wide guardrail and raised pavement marker projects are currently under consideration. The district recommends candidates which will not be covered by a 3R project in the near future.

2. *Are any low-cost, light-duty countermeasures considered for low-volume locations?*

Iowa For intersections, an incremental approach is taken in considering countermeasures, starting from low-cost improvements, e.g. extra signs, and moving up to the high-cost alternatives, such as signals. Horizontal curves have a similar hierarchy, which includes wider edge lines, button delineators, rumble strips, and paved shoulders. Examples of non-programmed improvement action:

A. District Office: Improvements on private property or minor grading
B. Office of Right of Way: Utility or billboard changes
C. District Office and/or Office of Maintenance: Flashing beacons, signing, paint striping

Programmed project responsibilities:

A. Office of Program Management: Programs as funds become available
B. Office of Road Design: Obtains clearances, conducts field reviews
C. Office of Construction: Monitors Project construction activity

Kansas Some examples are larger stop signs and diverging chevron patterns at "T" intersections.

Missouri MHTD classifies safety improvements into three types by cost range:

$50,000 and up:	High hazard improvement; usually entails rebuilding, right-of-way acquisition, and relocation of utilities; usually contracted
$12,000 - 50,000:	Medium improvement; modifications such as increasing radii or adding mast arms at intersections; materials or labor may be contracted
$0 - 12,000:	"120 program"; low-cost improvements such as signs or striping; usually performed by district crews

Low-cost improvements for low-volume roads are usually made by districts as part of the "120 program".

Nebraska Spot improvements, such as attaching guardrail to bridge wall or improving delineation, are often made, but again, 3R projects usually cover these deficiencies.

3. *Are safety improvements incorporated into 3R projects?*

Iowa Yes, minor improvements are, such as guardrail upgrading, culvert headwall removal, bridge retrofits, and driveway entrance slopes. Iowa classifies its highways into four service levels:

A: freeways
B: expressways
C: important collectors
D: other collectors (900-1500 ADT)

The lowest volume roads are county collectors which belong to the "900 system". The 3R safety design process begins with a review of accident data for the proposed section. Any sites with high accident frequencies are examined for patterns. A field review is conducted to help identify any dangerous elements. Alternative concepts are developed, and benefit/cost analyses are performed for each alternative. Then a review meeting is held with the district. Because 3R standards have not yet been approved in Iowa, exceptions to reconstruction standards must be approved by FHWA. New 3R standards have been drafted and are awaiting FHWA approval:

Design Speed	55 mph
Level of Service	C
SSD	550 ft
Max Deg of Curve	6 deg
Max Grade	6%
Lane Width	12 ft
Shoulder Width	6 ft
Shoulder Type	Granular
Foreslope	3:1
Normal Ditch	4 ft x 8 ft
Backslope	2.5:1
Transverse Slopes	6:1
Vertical Clearance	16.5 ft

Some of the proposed design guidelines for service level D (low-volume):

Pavement should be 18 feet or wider
Less than structural overlay
Emphasis on providing a good driving surface only
Culverts seldom extended
Guardrail upgrading to be considered
Granular fillet on shoulders
Subdrain installation to be considered
Safety dike with no right-of-way requirement to be considered
May consider repair of pavement surface only
Low cost
Widening may be programmed only when the pavement requires resurfacing

The whole design process takes about two years.

Kansas KDOT has a Safety Set-Aside Program with an annual budget of about $300,000. The projects in this program, which include mostly signals and intersection geometrics, can be federally funded as 3R projects. This program is under the administration of the Traffic Engineering Bureau. Most resurfacing projects in Kansas are not programmed as 3R projects, rather, the Bureau of Construction and Maintenance conducts an annual pavement inventory, and programs overlays as part of maintenance. Only about three or four true 3R resurfacing projects are programmed each year. The amount of right-of-way required is a major factor in determining whether 3R or complete reconstruction is necessary. Safety, however, is not a primary concern in the programming of 3R projects. Kansas groups its highways into five classes:

A: Interstate routes
B: Primary arterials
C: Other arterials
D: Intercounty connectors
E: Local collectors

These classes are independent of volume. A set of 3R standards has been developed, and these are based on both class and volume. The AADT groupings are 0-399, 400-874, 875-1749, 1750-3499, and 3500+. Also, the amount of heavy commercial traffic can be used in place of total volume, whichever requires the higher group. The heavy commercial groups are 0-49, 50-99, 100-299, 300-599, and 600+. For volumes greater than 750 AADT, horizontal curves 15 mph or more below the regulatory speed should be individually considered for possible reconstruction as may be warranted by accident history, while for AADTs below 750, additional warning signs and/or markings should be considered. Crest vertical curves with AADT greater than 1500 and safe speeds 15 mph or more below the regulatory speed should, if cost-effective, be flattened to at least 45 mph, but to the speed limit if additional right-of-way can be obtained. If AADT is less than 1500, the curve is retained, unless the road is reconstructed for other reasons. The cost-effectiveness of roadside treatments should clearly be demonstrated before further consideration is warranted during a resurfacing project. 3R projects should carefully consider these elements: earth slopes, clear zones, guardrail, and culverts.

Missouri In Missouri, the central office assigns a mileage allocation to each district. Districts select their "worst miles" of pavement up to their allocations. A central office team inspects and visually rates these sections. Elements such as guardrail end treatments, culvert length, and mailboxes are noted in the pre-design field review and addressed in the 3R concept reports, as well as accident data. Districts then program 3R projects within their total construction program funding allocations, following central office rules as to the rating scores that warrant a 3R project. Nearly all construction resurfacing is federal-aid. Maintenance resurfacing (mainly on low-volume roads) is selected by central office maintenance division (for larger projects) or by districts (for small projects) within their funding allocations. Missouri does not have 3R standards; exceptions to construction standards must be approved through the FHWA district office.

Nebraska Yes, in addition to pavement concerns, each section of highway is reviewed for safety deficiencies. District engineers prioritize 3R projects in the 5 to 20 year program. When a project is scheduled, an engineering review is performed by the Project Development Division. Elements considered include alignment, pavement condition, traffic, and function. Accident reports are reviewed to identify patterns, and photologs and/or field reviews locate potential obstacles. Projects are designed by the Roadway Design Division. About 43 projects are scheduled for fiscal year 1994, and 500 miles of 3R per year is NDOR's goal. Nebraska has 3R minimum design standards different from new construction standards; these are listed below. Also, a Needs Study was completed in 1988; these standards are listed in parentheses.

	400-1700 ADT	<400 ADT
Design Speed	55 mph	55 mph
Max Deg. of Curve	12.25	12.25
Max Grade Percent	existing	existing
Surface Lane Width	12 ft (12 ft)	11 ft (12 ft)
Min Shoulder Width	3 ft (6 ft)	2 ft (6 ft)
F.O. Clearance	12 ft (20 ft)	12 ft (12 ft)
SSD	40 mph (45 mph)	40 mph (40 mph)
Bridge Width*	36 ft (36 ft)	32 ft (32 ft)

* Special study areas will allow bridges to be used in place if within 4' of the desired roadway width.

Whenever possible, the Needs Study values are used instead of the minimum design standards.

D. Safety Program Planning

1. *How is the safety program administered (e.g. safety committee)? How often are meetings? How often is programming done (annually, quarterly, monthly)?*

Iowa The Bureau of Transportation Safety selects locations from the Safety Candidates List and submits them to the State Highway Commission, which has authority over all construction projects. The Commission meets monthly, and usually 5 or 6 HES projects are approved per year. Traffic Safety Improvement Projects are reviewed by a different committee within the Bureau of Transportation Safety, they are approved by the Highway Division Director and the Chief Engineer. About $3.5 million is available annually for TSIPs, with the maximum funding for any single project set at $500,000; 30-40 TSIPs are approved annually.

Kansas Every two years, Kansas cities, with population greater than 5000, may recommend five locations to the Traffic Engineering Bureau. The Bureau staff selects the projects for the two year period. Lettings occur monthly. The Bureau of Local Projects administers projects for cities under 5000 population.

Missouri	Missouri does not have a safety committee, per se. Each of the 10 highway district offices considers the high-hazard locations within the district and recommends improvements. The economic analyses are performed by the district offices using procedures defined by the state. The Maintenance and Traffic Division selects from these 100 projects and presents them to the Planning Division. Field reviews are conducted by district officials. Projects in the 120/medium improvement program are implemented within one to three months.
Nebraska	NDOR has a safety committee in charge of programming safety projects which meets monthly.

2. *Are dynamic programming algorithms used in planning projects?*

Iowa	A program was tested recently that scheduled projects for five years, but it has not been incorporated into the planning process.
Kansas	None are used at this time.
Missouri	No algorithms are used; the Maintenance and Traffic Division selects the projects with the best B/C ratios.
Nebraska	No algorithms are used; the committee selects from the projects with the best B/C ratios.

3. *What role does public input play in the programming process?*

Iowa	The most effective means for the public to get involved is in the metropolitan planning organizations and other local agencies; TSIP recommendations begin at this level, and the agencies look for public input.
Kansas	The public can appeal to the city to recommend a project to the state, also, citizens may request safety studies for a location.
Missouri	Public meetings are held for informational and feedback purposes.
Nebraska	Local agencies are closely involved in the process, often initiating consideration of certain projects and working with the committee. Informal public information

meetings are held annually in each district, in accordance with the Traffic Improvement Program.

4. *Are enough projects programmed to keep pace with federal safety funding?*

Iowa	Enough projects are approved, but complications in bidding sometimes endangers those funds.
Kansas	Yes, and KDOT often seeks unused funds from other states for extra projects.
Missouri	Plenty of projects are programmed.
Nebraska	Over the past few years, enough projects have been programmed to keep pace with federal funding levels, but the large design workloads make it difficult to bid the projects before funds expire. As funding levels increase, this problem will need further attention.

5. *Do you feel that programming procedures accommodate low-volume hazardous locations adequately?*

Iowa	Yes, because the identification process incorporates accident rate.
Kansas	Yes.
Missouri	No. High numbers of accidents or spectacular events are necessary to get the attention of safety projects, and these are usually intersections. The "expected values" program will help solve this problem.
Nebraska	The most common means of correcting safety problems is during 3R projects. Most low-volume roads concerns are addressed in this way also. Few separate safety projects are programmed for low-volume-roadway hazardous locations.