Evaluation of Safety Impact of Highway Projects

HASHEM R. AL-MASAEID, KUMARES C. SINHA, AND THOMAS KUCZEK

An empirical Bayesian approach to evaluate the safety impact of highway projects at a group of sites level was developed. Rural traffic accident data from the state of Indiana were used. The Bayesian methodology was illustrated using examples of wedge and level and resurfacing projects. The results indicated that wedge and level and resurfacing activities did not have a significant effect on the level of the expected number of accidents or accident rates at 95 percent probability level on Indiana's two-lane rural roads having traffic volumes less than 4,000 vehicles per day.

The purpose of the research reported in this paper is to develop an empirical Bayesian approach to evaluate the safety impact of highway projects in reducing accident frequency, accident severity, or the potential for accidents. The results are used to determine accident reduction factors (ARFs).

Four methods were reviewed. First, the simple before-and-after method is based on the observed number of accidents. Because of the regression-to-mean phenomenon, this method tends to overestimate the effectiveness of highway safety improvements (*1*). Second, the before-and-after-with-matched-control-group method, although theoretically sound, is difficult to apply in practice (*2*). The third method, a modeling technique, cannot completely explain all variations in traffic accidents; thus its use is limited (*3*). And fourth, the Bayesian approach was only partially addressed by Hauer (*4,5*) because his evaluation was based on comparisons observed in the after period with the predicted values at site level. Moreover, probability levels were not computed to declare any significance in the results.

The present study applied Bayesian statistics to estimate the expected number of accidents (mean in the long term) and the expected accident rate. Bayesian statistics were used for three main reasons. First, the Bayesian approach is a probabilistic method capable of augmenting the most recent information with the available historical data or prior knowledge to achieve better estimates, reducing associated uncertainties. Second, the Bayesian approach permits pooling of information for a population or set of sites as well as for individual sites, allowing better use of the available information for prediction purposes. Third, the performances of the Bayesian models to predict the expected number of accidents and accident rate were investigated (*6*), and they provided legitimate estimates specifically at a group of sites level.

H. R. Al-Masaeid, Jordan University of Science and Technology, Irbid, Jordan. K. C. Sinha and T. Kuczek, Purdue University, West Lafayette, Ind.

MODEL DEVELOPMENT

In the analysis, two assumptions were made:

1. Traffic accidents at any particular location fit the Poisson distribution in the absence of any highway improvement.
2. The expected number of accidents λ is a random variable with a gamma probability distribution over the population of a number of sites. The expected accident rate ρ is a random variable with a gamma probability distribution.

On the basis of the assumptions, if x denotes the observed number of accidents at a particular location in 1 year, x has a Poisson distribution $P(x/\lambda)$ with mean λ so that

$$P(x/\lambda) = \lambda^x e^{-\lambda}/x! \qquad x = 0, 1, 2 \tag{1}$$

Considering λ (mean in the long run) as a continuous random variable within the population of locations and $f(\lambda)$ as its probability density function with parameters β and α, the prior distribution of λ is

$$f(\lambda) = a^\beta \lambda^{\beta-1} e^{-\alpha\lambda}/\Gamma(\beta) \qquad \lambda, \beta, \alpha > 0 \tag{2}$$

where $\Gamma(\beta)$ is the gamma function.

The parameters of the prior distribution are estimated from the sample statistics of similar locations as follows:

$$\hat{\alpha} = \bar{x}/(s^2 - \bar{x}) \tag{3}$$

$$\hat{\beta} = \bar{x}^2/(s^2 - \bar{x}) \tag{4}$$

where $\bar{x}$ and s^2 are the sample mean and sample variance calculated from all similar sites in the population.

The next step in the analysis is to combine the prior knowledge and the new information to obtain the posterior distribution of λ. This is accomplished through the application of the Bayes' theorem. Thus, if x is the number of accidents at a given location, the posterior distribution of λ is of gamma type with parameters

$$\beta' = x + \beta \tag{5}$$

and

$$\alpha' = 1 + \alpha \tag{6}$$

Having obtained the posterior distribution of λ at each location, the next step is to obtain the distribution of the total expected number of accidents λ_t at a group of n similar locations. This is accomplished by using the convolution principle. Thus, if $\lambda_1, \lambda_2, \ldots, \lambda_n$ are independent random variables, the total expected number of accidents λ_t is given by

$$\lambda_t = \sum_{i=1}^{n} \lambda_i \quad (7)$$

where λ_i is the expected number of accidents at location i.

Moreover, convolutions of n probability density functions each having posterior parameters of β_i' and α' have a gamma probability density function (*7*). Therefore, λ_t has a gamma probability density with parameters $\Sigma\beta_i'$ and α', as shown below:

$$\sum \beta_i' = n\beta + \sum x_i \quad (8)$$

$$\alpha' = 1 + \alpha \quad (9)$$

The expected mean and variance of λ_t are

$$E(\lambda_t) = \left(n\beta + \sum_{i=1}^{n} x_i\right)/(1 + \alpha) \quad (10)$$

$$Var(\lambda_t) = \left(n\beta + \sum_{i=1}^{n} x_i\right)/(1 + \alpha)^2 \quad (11)$$

Safety impacts may be estimated by comparing the number of accidents that probably would have occurred (according to the posterior distribution before improvement) with the actual observed at the location after the improvement. However, when doing so, the predictive distribution of the number of accidents will be of the negative binomial form (*8*), which has high variance. Therefore, a large reduction in the observed number of accidents in the after period is necessary to dictate any significant difference specifically at the site level.

The evaluation method can be enhanced by using the expected number of accidents, which has less variability than the number of accidents. To do so, it is necessary to assume that the expected numbers of accidents before and after improvements are independent random variables.

Thus, if β' and α' are the posterior parameters of the expected number of accidents in the before period λ_b, and the expected number of accidents in the after period λ_a has posterior parameters k' and γ', the joint probability density function is

$$f(\lambda_b, \lambda_a) = \begin{cases} \dfrac{\alpha^{\beta'}\lambda_b^{\beta'-1}e^{-\alpha'\lambda_b}}{\Gamma(\beta')} * \dfrac{\gamma^{k'}\lambda_a^{k'-1}e^{-\gamma'\lambda_a}}{\Gamma(k')} & \lambda_b, \lambda_a, \alpha', \beta', \gamma', k' > 0 \\ 0 \quad \text{otherwise} \end{cases} \quad (12)$$

Therefore, to evaluate the safety effectiveness of a given improvement, one must compute the probability of the expected number of accidents in the after period, λ_a, being less than the expected number of accidents in the before period. That is,

$$p(\lambda_a < \lambda_b) > \theta \quad (13)$$

where θ is the predetermined probability level at which the improvement is declared effective in the reduction of the expected number of accidents.

The preceding probability statement can be expressed as follows:

$$p(\lambda_a < \lambda_b) = 1 - p(\lambda_a > \lambda_b)$$
$$= 1 - \int_{RS}\int f(\lambda_b, \lambda_a)d\lambda_b d\lambda_a \quad (14)$$

where RS is the region satisfying $\lambda_a > \lambda_b$. Since λ_a and λ_b take only positive values,

$$p(\lambda_a < \lambda_b)$$
$$= 1 - \int_0^{\infty}\int_{\lambda_b}^{\infty} \frac{\gamma^{k'}\lambda_a^{k'-1}e^{-\gamma'\lambda_a}}{\Gamma(k')} * \frac{\alpha^{\beta'}\lambda_b^{\beta'-1}e^{-\alpha'\lambda_b}}{\Gamma(\beta')} d\lambda_a d\lambda_b \quad (15)$$

The preceding integral is equal to

$$p(\lambda_a < \lambda_b)$$
$$= 1 - \sum_{j=0}^{k'-1} \left[\frac{\gamma'}{\alpha'}\right]^j \left[\frac{\alpha'}{\alpha' + \gamma'}\right]^{\beta'+j} * \frac{\Gamma(\beta' + j)}{\Gamma(j + 1)\Gamma(\beta')} \quad (16)$$

On the other hand, the use of the accident rate method to assess the safety impact of highway improvement is valuable because the accident rate method is sensitive to variations in traffic volume. The probability of x accidents at a site i with accident rate ρ and volume V_i is given by

$$P(x|\rho, V_i) = \frac{(\rho V_i)^x e^{-\rho V_i}}{x!} \quad (17)$$

where V_i is the normalized average daily traffic volume ($ADT*365/10^6$) at a given site.

The second assumption implies that the probability distribution function of the accident rate at a site has a gamma distribution; that is, the parameters of the gamma distribution can be estimated by matching the mean and variance of the observed accident rates [R and Var (R)] from a sample with the mean and variance of negative binomial distribution normalized by the volume. Morris (*9*) pointed out that the estimates of gamma parameters based on the method of moments are as follows:

$$\hat{\nu} = V^* * \overline{R}/(V^* * S^2 - \overline{R}) \quad (18)$$

$$\hat{a} = \overline{R}\nu \quad (19)$$

where

- a and ν = shape and scale parameters of gamma distribution, respectively;
- V^* = harmonic mean of traffic volumes (normalized $V_1, V_2, \ldots, V_n$);
- S^2 = variance of the observed accident rates obtained from a sample of sites; and
- $\overline{R}$ = mean of accident rates in the population of sites ($R_1, R_2, \ldots, R_n$).

The mean and variance are computed from a sample as follows:

$$\overline{R} = \left(\frac{1}{n}\right) \sum_{i=1}^{n} R_i \tag{20}$$

$$S^2 = \left(\frac{1}{n-1}\right) \sum_{i=1}^{n} (R_i - \overline{R})^2 \tag{21}$$

where R_i is the accident rate at Site i and n is the number of sites in the selected sample.

Once the parameters of prior distribution have been determined, the next step is to combine the prior information with the site-specific data to obtain the posterior distribution. Thus, if x_i is the number of accidents and V_i is the normalized traffic volume on a given site, the posterior distribution of ρ is of gamma form with parameters

$$\nu_i' = \nu + V_i \tag{22}$$

and

$$a_i' = a + x_i \tag{23}$$

At the group of sites level, the total expected accident rate is given by the sum of individual accident rates. Thus, the total expected accident rate ρ_t for a group of n sites is given by

$$\rho_t = \sum_{i=1}^{n} \rho_i \tag{24}$$

where ρ_i is the expected accident rate of Site i.

Moreover, the expected value and variance of ρ_t are

$$E(\rho_t) = \sum_{i=1}^{n} (a_i'/\nu_i') \tag{25}$$

and

$$Var(\rho_t) = \sum_{i=1}^{n} (a_i'/\nu_i'^2) \tag{26}$$

Parameters of ρ_t can be computed by matching moments from Equations 25 and 26. The parameters can be approximated as follows:

$$\nu = \left(\sum a_i'/\nu_i'\right) \Big/ \left(\sum a_i'/\nu_i'^2\right) \tag{27}$$

$$a = \left(\sum a_i'/\nu_i'\right)^2 \Big/ \left(\sum a_i'/\nu_i'^2\right) \tag{28}$$

The general approach used in the evaluation of safety impacts according to the expected number of accidents will be used herein. To evaluate safety impacts according to the accident rate model, it is assumed that accident rates before and after improvements are independent random variables. Hence, if ρ_b is the before accident rate with posterior parameters a' and ν', and ρ_a is the after accident rate with posterior parameters b' and u', then a highway project is efficient in reducing accident rate if and only if the probability that ρ_a is less than ρ_b exceeds a predetermined probability level (say θ). That is,

$$p(\rho_a < \rho_b) > \theta \tag{29}$$

where $p(\rho_a < \rho_b)$ can be approximated from the following derived equation:

$$p(\rho_a < \rho_b) = 1 - \sum_{j=1}^{b'-1} \left[\frac{u'}{\nu'}\right]^j \left[\frac{\nu'}{\nu' + u'}\right]^{a'+j} * \frac{\Gamma(a' + j)}{\Gamma(j + 1)\Gamma(a')} \tag{30}$$

METHODOLOGY

In this research, a simple before-and-after methodology based on the Bayesian approach is presented to evaluate safety impacts of highway projects. In the evaluation both the expected number of accidents and the expected accident rate at a group of sites (total expected number of accidents and total expected accident rate) were used, rather than the expected number of accidents or expected accident rate at a site level because at site level a very large change in accidents is needed to judge significant results. The before-and-after methodology based on the Bayesian approach can be summarized as follows:

1. In the before period, prior parameters estimated from previous knowledge are augmented with the most recent information to estimate either the expected number of accidents or the expected accident rate. The resulting estimated value represents the best estimate of the expected value in the future period in the absence of any highway improvements. In the research, 2 years of accident experiences at all sites represented the before period. The prior parameters were estimated from the first year, whereas the sample data (sample likelihood) was drawn from the second year. The second year provided data immediately preceding the implementation of an improvement project.
2. In the after period, the prior parameters were estimated from the data of the first year after improvement. The prior parameters were augmented with the available information from the second year in the after period to estimate the posterior parameters and to predict either the expected number of accidents or the accident rate. If a large change in the average daily traffic volume is noted, adjustment of parameters according to the change in volume is necessary if the expected number of accidents is used. The predicted value based on the posterior distribution in this stage then represents the best estimate of the total expected number of accidents or the total accident rate after the installation of a highway improvement.

In fact, prior and posterior information need not be separated in time if there are a large number of similar sites to estimate prior parameters. However, similarity is a subjective matter. Therefore, it was believed that prior parameters estimated from the sites under investigation (that will receive or received an improvement) would narrow down the similarity and provide more reliable results. In this case, separation is necessary, at least from a theoretical point of view, because it is impossible to estimate prior and posterior parameters from the same set of data. In addition, the separation provided a means to incorporate the accident data within 2 years in each period. The regression-to-mean effect is defined as the difference between the posterior mean and the past observed mean. In this methodology, comparisons were carried between posterior means; therefore, the regression-to-mean effect is not a considerable issue.

3. Comparisons of predicted values from the before and after periods were used to estimate the percentage change in the values of the total expected number of accidents or total accident rate. Moreover, if the evaluation was based on the total expected number of accidents, Equation 16 was used to compute the probability that the total expected number of accidents in the after period is less than the total expected number of accidents in the before period for the group of improved sites. Similarly, Equation 30 was used to compute the associated probability level if the evaluation was based on the total expected accident rate.

DATA DESCRIPTION

Rural traffic accident data from the state of Indiana were used in the study. Traffic accident data from police records for 1982 through 1989 were used to estimate the safety impact of wedge and level and resurfacing projects. The wedge and level and resurfacing projects were selected mainly because of the availability of a large number of sites with these activities.

In the study, a site is defined as a section of rural highway 1 mi long irrespective of its past accident history. Sites of intersections and interchanges were excluded. Annual average daily traffic volumes on each site were obtained from Indiana Department of Transportation volume statistics publications. Moreover, detailed maps were extensively used to define the boundaries of each site or a group of consecutive improved sites.

Evaluation of the Safety Impact of Wedge and Level Improvement

Basically, wedge and level activity is not a safety improvement. However, in this paper its safety impact was evaluated as an example to present the methodology. Most of the wedge and level projects in the sample were implemented on non-Interstate highways in Indiana from 1983 through 1986. Almost all affected sections had annual average daily traffic volumes of less than 4,000 vehicles per day. A sample of 190 sites (190 mi) was selected to estimate the safety impact of wedge and level activity.

To apply the developed methodology, accident experiences of sites for 2 years before and 2 years after improvement were required. As mentioned earlier, the first year in the before period was used to estimate the before prior parameters, and the accident experience of all sites in the second year (immediately before the year of implementation) was used to update the prior parameters and to compute the posterior parameters. In the same manner, in the after period, accident experience in the year immediately after the year of implementation was used to estimate the prior parameters, and accident experiences of all sites in the second year were combined with prior to estimate posterior parameters and to predict the expected number of accidents or the accident rate.

Estimation of Parameters and Other Issues

For the estimation of prior parameters two samples were selected randomly from the population of improved sites in the before and after periods. Each sample had 60 sites. These samples were used to estimate prior parameters of the expected number of accidents and accident rate and then to show that the marginal distribution of the observed number of accidents approximately followed the negative binomial distribution and, as a result, the expected number of accidents or accident rate had a gamma probability distribution. The goodness-of-fit results indicated that the marginal distribution of the observed number of accidents followed the negative binomial distribution. Therefore, the assumption of the gamma distribution adopted in the derivation of Equations 16 and 30 is not unreasonable.

To augment the prior information, the sample data (sample likelihood) from all sites (190 sites) in the before and after period were used. The sample data were combined with prior parameters to predict the expected number of accidents or accident rates in the before and after periods. However, before the final assessment of the wedge and level activity, it was instructive to check for the assumption made in the derivation of Equations 16 and 30. The assumption stipulated that the expected number of accidents and accident rates in the before and after period are independent random variables. For this purpose, the posterior parameters for each site were computed from prior parameters and the site specific data before and after improvements. The results from the 190 sites are shown in Figures 1 and 2 for the number of accidents and accident rate, respectively. The estimated correlation coefficient between the before and after values of the expected number of accidents was 0.00396, and the corresponding coefficient for the accident rate was −0.00059. The correlations were very small and not significant; therefore, the assumptions of independence are not unreasonable.

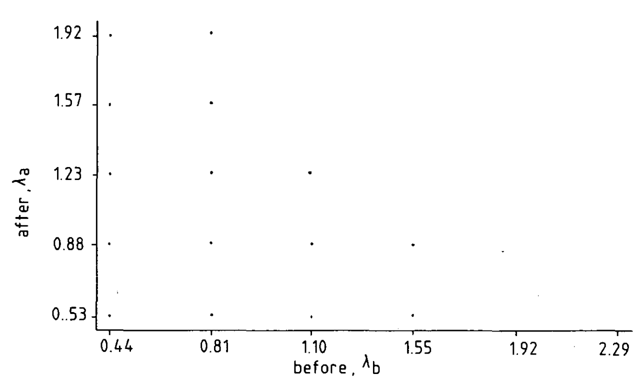

FIGURE 1 Expected number of accidents in the before and after improvements for wedge and level improvements.

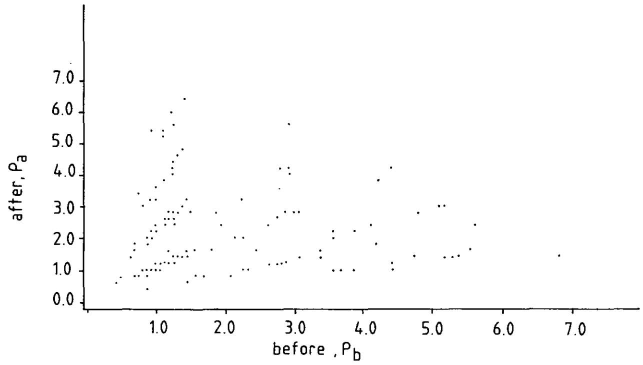

FIGURE 2 Expected accident rates in the before and after improvements for wedge and level improvements.

Results of Evaluation

Wedge and level activities were evaluated according to the expected number of accidents model and the accident rate model. The evaluations were performed at a group of sites level (population of the improved sites). Results of analyses according to the expected number of accidents model are given in Table 1, and results of evaluation according to the accident rate model are summarized in Table 2. Since there was a considerable increase in the total average daily traffic volume (the total volume on all sites changed from 181,475 vehicles per day in the before period to 188,890 in the after period), the decision with respect to the expected number of accidents was made on the adjusted results (transformation results). The adjustment was made as indicated in Table 1. The results indicated that the estimated mean number of traffic accidents increased by 8.06 after implementation of the wedge and level improvements. However, the probability test from Equation 16 indicated that the increase was not significant at 5 percent level [$P(\lambda_a < \lambda_b) = 0.131$]. The increase in the accident rate after the wedge and level improvement was 7.70 percent. The probability test according to Equation 30 indicated that the increase in the accident rate was not significant at 5 percent level [$P(\rho_a < \rho_b) = 0.188$].

Evaluation of the Safety Impact of Resurfacing Improvements

Resurfacing projects were implemented on both undivided and divided roads. However, only undivided U.S. and state roads had sufficient numbers of improved sites. The total number of sites on undivided U.S. and state roads that were used in the evaluation was 95 (95 mi). The annual average daily traffic volume on these sites was less than 4,000 vehicles per day in the year of implementation.

In the before period, prior parameters for the expected number of accidents and accident rate were estimated from accident experience and traffic volume in the first year of the 2 years preceding the resurfacing. In the after period, prior

TABLE 1 Estimation of Accident Reduction Factor Associated with Wedge and Level Improvements According to the Expected Number of Accidents Model

Prediction for Period		Before period	After Period
Prior Parameters	α	1.7073	1.8862
	ß	1.1950 (1.3737)*	1.5400
Sample Data	$\sum n_i$	190	190
	$\sum x_i$	115 (119.7)**	146
Convoluted Parameters	α'	2.7070	2.8862
	ß'	342.00 (380.71)*	439.00
Traffic Volume	Prior	66695	76670
	Sample	181475	188890
Predicted Values		126.36 (140.66)*	152.00
Accident Reduction Factor	Unadjusted=((126.36-152.00)/126.36)*100=-20.30 %		
	Adjusted=((140.36-152.00)/140.36)*100=-8.06%		

* Adjusted according to traffic volumes.
** 115 · (188890/181475).

TABLE 2 Estimation of Accident Reduction Factor Associated with Wedge and Level Improvements According to the Accident Rate Model

Prediction for Period		Before period	After Period
Prior Parameters	α	0.714325	0.863700
	ν	0.414030	0.493265
Sample Data	$\sum n_i$	115	146
	$\sum x_i$	66.2384	68.9450
Expected Accident rate	MEAN	354.7944	382.0959
	VARIANCE	541.1785	500.8576
Estimated Parameters	α'	333.00	291.00
	ν'	0.65650	0.7620
Accident Reduction Factor	A.R.F.=((354.7944-382.0959)/345.7944)*100=-7.70 %		

parameters for the expected number of accidents and accident rate were estimated from the first year following the improvement. In the before period the sample data were from the year preceding the implementation, and in the after period the sample data were from the second year after implementation. Posterior parameters were used to predict the expected number of accidents and rate of accidents in the before and after periods. On the basis of the posterior parameters, the correlation between the expected number of accidents and the expected accident rates in the before and after periods were 0.0943 and 0.11077, respectively. These correlations were not significant at 5 percent level.

Results of Evaluation

Resurfacing improvements were evaluated according to the expected number of accidents and accident rate models. Results of the evaluation based on the expected number of accidents model are summarized in Table 3. Results of the evaluation according to the accident rate model are summarized in Table 4.

Table 3 indicates that the level of traffic accidents increased after implementation of the resurfacing projects. However, the total average traffic volume also increased from before to after periods (from 212,195 to 235,872 vehicles per day). The accident number was therefore adjusted for traffic volumes. The adjusted results indicated the increase in the expected number of accidents to be about 7.66 percent. According to Equation 16 the increase was not significant at 95 percent level [$P(\lambda_a < \lambda_b) = 0.163$]. Table 4 indicates that the increase in the rate of accidents in the after period was 11.10 percent. However, the computed probability level for Equation 30 indicates that with 5 percent probability level the increase was not significant [$P(\rho_a < \rho_b) = 0.081$].

DISCUSSION OF RESULTS

This paper presented a methodology to evaluate the safety impact of highway projects based on the Bayesian approach. The methodology was applied to evaluate two types of highway projects on rural undivided U.S. and state roads having annual average daily traffic volumes of less than 4,000 vehicles per day. The examples were drawn from wedge and level projects and resurfacing projects. These projects are not necessarily safety improvement projects, and the results of analyses indicated that there was no significant difference in the level of traffic accidents before and after implementation of wedge and level and resurfacing improvements.

The aim of wedge and level improvements is to wedge rutting depression and holes in the pavement and to provide acceptable leveling of the roadway cross section. Longitudinal rutting depression on roadway sections causes water and snow or ice to accumulate on the pavement surface, and as a result vehicles are more likely to be involved either in hydroplaning accidents or in slippery pavement accidents. Rutting depression, transverse depression, and excessive lack of roadway leveling are main causes of loss of control accidents and driver fatigue accidents. Thus, the promise of wedge and level as safety improvements is to reduce these types of accidents and to provide better driving conditions. Results of analyses indicated that the number of accidents and the rate of accidents increased after implementation of these improvements. The

TABLE 3 Estimation of Accident Reduction Factor Associated with Resurfacing Improvements According to the Expected Number of Accidents Model

Prediction for Period		Before period	After Period
Prior Parameters	α	1.6683	1.9100
	ß	1.7934 (1.9323)*	2.2920
Sample Data	$\sum n_i$	95	95
	$\sum x_i$	104 (115.0)**	132
Convoluted Parameters	α'	2.6683	2.9100
	ß'	274.40 (298.00)*	350.00
Traffic Volume	Prior	82640	89045
	Sample	212195	235872
Predicted Values		102.83 (111.63)*	120.19
Accident Reduction Factor	Unadjusted=((102.83-120.19)/102.83)*100=-16.88 %		
	Adjusted=((111.63-120.19)/111.63)*100=-7.66%		

* Adjusted according to traffic volumes.
** 104 * (235,872/212,195)

TABLE 4 Estimation of Accident Reduction Factor Associated with Resurfacing Improvements According to the Accident Rate Model

Prediction for Period		Before period	After Period
Prior Parameters	α	5.286000	1.200000
	ν	3.710000	0.810300
Sample Data	$\sum n_i$	104	132
	$\sum x_i$	77.4512	86.0933
Expected Accident rate	MEAN	134.1503	149.0442
	VARIANCE	29.9145	97.1015
Estimated Parameters	α'	600.00	229.00
	ν'	4.4730	1.5350
Accident Reduction Factor	A.R.F.=((134.1503-149.0442)/134.1503)*100=-11.10 %		

increase was not significant. The increase was probably associated with two factors that are correlated with traffic accidents. First, the improvement of roadway conditions probably encouraged drivers to increase their operational speed, and second, wedge and level improvements applied to a limited area of the pavement may not have improved pavement skid resistance.

In reviewing the available literature, no reference was found that reported the safety impact of the wedge and level improvement as a single activity. However, wedge and level can be implicitly included under patching activities. If so, Creasey and Agent (*10*), on the basis of a literature review, indicated that resurfacing, patching, drainage, and deslick improvements reduced the expected level of traffic accidents by 16 percent.

Results of analyses performed in this study indicated that levels of traffic accidents (expected number of accidents and rate of accidents) increased after resurfacing improvements, but the increases were not significant at 5 percent probability level. One probable explanation for the increase is that resurfacing improved the quality of driving; therefore, traffic operational speeds increased, and the resurfacing impact on the level of accidents could not be compensated for by a small improvement in the skid resistance. The soundness of the result can be judged by comparisons with other available studies. Creasey and Agent (*10*) developed accident reduction factors for various highway improvements in Kentucky. Their recommendation was based primarily on engineering judgment and some before and after evidence. In another study (*11*), an empirical relationship was developed between the wet-pavement accident rate and skid resistance. The relationship indicated that the wet-weather accident rates drop for all rural highway classes when the pavement skid resistance increased. But on the basis of data from the resurfacing, restoration, and rehabilitation program, Brinkman (*12*) reported that resurfacing did not have a significant effect on the mean skid number of the tested sections selected in the study. In addition, on the basis of data from the same program, Tignor and Lindley (*13*) analyzed information from nine states and concluded that resurfacing increased the rate of accidents by about 2.2 percent, but the increase was not significant at 5 percent level. In the same study, Tignor and Lindley (*13*) found that resurfacing improvements resulted in an increase in the skid resistance of a 32-mi two-lane rural highway section in Alabama. The accident rate in this section increased by 11.85 percent after resurfacing, but the increase was not significant at 5 percent level. Thus, the results of the analyses performed in the present study are compatible with results obtained from others and a large data base for evaluating the effect of resurfacing improvements on the level of traffic accidents.

CONCLUSION

A methodology to evaluate the safety impact of highway improvements was developed. The evaluation was based on the expected number of accidents and expected accident rate, which were developed according to the Bayesian approach. The methodology was applied to evaluate the impact of wedge and level and resurfacing projects. The results indicated that wedge and level improvements did not have a significant effect on the level of the expected number of accidents or rate of accidents at 95 percent probability level on undivided rural roads having average daily traffic volume less than 4,000 vehicles per day. The results also indicated that resurfacing projects did not have any significant impact at 5 percent probability level on the level of traffic accidents on the same type of roads. The results were generally compatible with the information available in the literature.

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