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Impacts of Resurfacing Projects With and Without Additional Safety Improvements

This digest summarizes the results of NCHRP Project 17-9(2), "Impacts of Resurfacing Projects With and Without Additional Safety Improvements." The objective of this study was to determine if resurfacing coupled with safety improvements resulted in a measurable difference in crash performance compared with locations that received only an asphalt overlay. Although the results of the study were inconclusive, individual site characteristics appear to greatly impact the safety effect of resurfacing. This digest is based on a draft final report prepared by W. E. Hughes, L. M. Prothe, and H. W. McGee of Bellomo McGee, Inc., and E. Hauer, Consultant.

SUMMARY

This digest describes the findings of a study to determine if there is a difference in the crash performance of resurfacing projects with and without safety improvements. Although the results were inconclusive, the study provides recommendations for conducting future studies and will be of interest to safety practitioners.

Drivers choose a speed on the basis of their familiarity and knowledge of the immediate area, visual cues provided by the roadway environment, and consideration of the posted speed limit, often in that order. Two of the visual cues provided to drivers are the quality of the roadway surface and the delineation of travel lanes. After a roadway is resurfaced, the improved ride quality and visual contrast created by new pavement markings on a smooth asphalt surface could create for the driver the impression of a safer road that can be traversed at a higher speed. Hence, the potential for increased crashes exists if additional roadway and roadside improvements do not accommodate the increased speeds.

NCHRP Project 17-9, "Effect of Highway Standards on Safety," investigated the effects of highway standards on safety and found major gaps in the understanding of the influence of design features on safety. One of those gaps was the impact of resurfacing with and without additional safety improvements. Although many studies have examined the effect of resurfacing on safety, few studies have differentiated between simple overlays and projects that include resurfacing, restoration, or rehabilitation (3R)-type safety improvements. Thus, Project 17-9(2) was initiated by NCHRP in 1995. This project is critical because of the implications of resurfacing (particularly in state and local agencies) and because of the continuing pressure on agencies to optimize the use of limited resources for transportation improvements. The objective of this research was to determine whether resurfacing coupled with minor and major safety improvements resulted in a measurable difference in crash performance compared with locations that received only an overlay of asphalt.

The literature review provided valuable insight into the methodology formulated for the analysis. For instance, regression to the mean and the random nature of data should be mitigated by selecting sites according to their pavement condition (and not their accident history), by using a long accident history (i.e., with 3–5 years), and by using a large sample size (i.e., a long stretch of highway). Additionally, using a reference group of sites accounts for unknown crash trends, and performing the crash analysis on a monthly basis accounts for any novelty effect. Finally, the crash analysis should segregate intersection and nonintersection crashes because resurfacing is believed to affect each differently.

Various data were collected from the states of Washington, California, Minnesota, New York, and Illinois. These data included resurfacing project data, roadway data, traffic data, and crash data. Each state's data were analyzed separately, using the empirical Bayes statistical analysis procedure, to determine the influence of resurfacing on the crash rate. The resulting percent reduction of the number of crashes indicated an inconsistency from state to state, and even between the different crash groups, regarding the effect of resurfacing on the roadway. Washington had an average reduction of 18 percent in the number of crashes, while Minnesota had an average increase of 25 percent. Further analysis of the data from these two states (i.e., a simple before-and-after comparison of crash rates) revealed yet more differing conclusions. In Washington, adding safety improvements to resurfacing work did not seem to reduce crashes, while in Minnesota, adding safety features did seem to provide an additional benefit.

The conclusions from the data analysis and the literature review indicate that the effect of resurfacing a roadway is clearly different within and among the states because of the difference in individual site characteristics. Additionally, the effect of adding safety improvements to resurfacing work also differed within and between the states compared. Engineering intuition indicates that there must be some key differences from site to site that will affect the safety of the site; however, such characteristics could not be identified in the data received by the researchers.

Examination of the data also provided some information regarding the "novelty effect" of resurfacing the roadway. But, as with the above conclusion, the results were inconsistent from state to state. Finally, the investigation of the effects of resurfacing was extended to focus on the road downstream of the resurfaced sections. The empirical Bayes analysis for each of the five states yielded no evidence to suggest that resurfacing adversely affected crash frequency downstream of the resurfaced road sections.

Both the analysis of the data that were provided for this project and the review of previous studies documented indicate that there is not a single consistent pattern of the effect of resurfacing among and within the states. A more promising methodology for this type of study would employ a before-and-after comparison, with randomized controls limited to sites in one or, at most, two states.

RESEARCH PROBLEM STATEMENT

After an existing pavement surface is replaced with a smooth black layer of asphalt and new pavement markings are added, the visual cues provided by the facility change from those previously in place. Drivers choose a speed using their familiarity and knowledge of the immediate area, visual cues provided by the roadway environment, and consideration of the posted speed limit, often in that order. Two of the visual cues provided to drivers are the quality of the roadway surface and the delineation of travel lanes. The improved ride quality and visual contrast created by new pavement markings on a smooth asphalt surface could create for the driver the impression of a safer road that can be traversed at a higher speed. Lacking additional roadway and roadside improvements to accommodate increased speeds, the potential for increased crashes exists. Resurfacing also creates a condition known as "bleeding" of the new pavement. Such a process leads to increased moisture on the roadway surface. This increased moisture may be an additional resurfacing-related cause of an initial increase in crashes.

Safety is only one area of concern for transportation agencies. In fact, decision makers in state and local transportation agencies must consistently address the competing objectives of maintaining the roadway network, reducing congestion, and improving safety. Funding in most departments is not generally adequate to completely satisfy all three objectives. Thus, programs for these objectives compete for the same pool of funds, and inherent tradeoffs must be made. Many agencies have determined that restoring pavement condition or rehabilitating bridges is their first priority. Roadside improvements may not receive funding because policy makers and decision makers are unsure of the cost-effectiveness of these improvements. Increased knowledge of the safety impacts of resurfacing and the effectiveness of associated safety improvements would enable transportation agencies to better distribute funding among projects and to better meet systemwide objectives.

Although many studies have examined the effect of resurfacing on safety, few studies have differentiated between simple overlays and projects that include 3R-type safety improvements. A TRB study examined the crash effect of resurfacing alone and of resurfacing in combination with a certain set of safety improvements for the state of New York (Hauer, Terry, and Griffith; 1994). The study did not attempt to differentiate the incremental effects of specific safety improvements that are often implemented in combination with resurfacing. As people involved in highway safety evaluations can readily attest, it is extremely difficult, if not nearly impossible, to discern incremental safety effects from crash data for projects in which multiple improvements are implemented concurrently.

Often, the characteristics of two-lane, rural road sections selected for resurfacing projects dictate the implementation of a set of unique safety improvements. Moreover, the scope of resurfacing projects varies widely. The contradictory results reported in different studies may, in part, be caused by the differences in the scope of the resurfacing projects. For example, in the New York State Department of Transportation (NYSDOT), resurfacing varies, from maintenance repaving by state forces of a 1.5-in. (3.8-cm), hot-mix asphalt overlay on a pavement rated fair (i.e., rated 6 on a scale of 0-10, with 10 being excellent) to a project in which the pavement is rated poor (i.e., rated 4 on the same scale) and in which the resurfacing consists of a truing and leveling course followed by a 2.5-in. (6.4-cm), two-course overlay. Thus, the term "resurfacing" can imply a wide range in project scope.

After the results of the TRB study by Hauer, Terry, and Griffith became available, there was concern that the crash rates might also increase after maintenance paving. Traffic engineers from NYSDOT compared the before-and-after crash rates for a 3-year period for maintenance paving projects. On a statewide basis, there was a 2-percent, statistically significant decrease in the number of crashes after maintenance paving. Some researchers have concluded that, most likely, there were no increases in speed after maintenance paving because the road was in a fair condition and the ride quality was still relatively good before paving. These researchers claim that speeds increase after resurfacing only when the "before" pavement condition both is poor and reduces the ride quality of the roadway. The state of New York's experience with the safety effects of resurfacing is used in this section as an example and is thought to represent similar circumstances in other states.

BACKGROUND

NCHRP Project 17-9 investigated the effects of highway standards on safety and found that major gaps exist in the understanding of the influence of design features on safety (McGee, Hughes, and Daily; 1995). Subsequently, eight research projects were identified to study this relationship. Of these projects, the investigation of crash impacts of resurfacing projects with and without additional safety improvements was considered to have the largest potential to advance the state of the art. Thus, Project 17-9(2) was initiated by NCHRP in 1995. This project is critical because of the great number of resurfacing projects, the lack of guidance for the design engineer on the safety implications of resurfacing (particularly in state and local agencies), and the continuing pressure on agencies to optimize the use of limited resources for transportation improvements.

NCHRP Project 17-9(2) was conducted in close coordination with NCHRP Project 3-56, "Systemwide Impact of Safety and Traffic Operation Design Decisions for Resurfacing, Restoration, or Rehabilitation." Highway agencies may consider additional improvements as part of resurfacing projects but not implement these improvements because they are not considered cost-effective or because the additional funds that would be required are deemed better spent elsewhere. NCHRP Project 3-56, which addresses the issue of cost-effectiveness of safety improvements, used the data collected in NCHRP Project 17-9(2). NCHRP Project 3-56 examines the hypothesis that post-resurfacing speeds are higher than pre-resurfacing speeds are. The scope of NCHRP Project 3-56 includes multilane nonfreeway facilities, which were not included in the scope of NCHRP Project 17-9(2).

OBJECTIVES

The need for NCHRP Project 17-9(2) was identified by the lack of available information on the safety effects of resurfacing and by the significant number of miles of rural two-lane roadways resurfaced each year in the United States. The objective of this research was to determine if resurfacing coupled with minor and major safety improvements results in a measurable difference in crash performance compared with locations that receive only an overlay of asphalt. The results of this study are intended to assist policy makers and engineers in determining when additional improvements, beyond simple resurfacing, are justified. Safety improvements are defined in this digest as roadway and roadside work, beyond resurfacing, that includes the following: shoulder or lane widening, obstacle removal, drainage work, guardrail, side slope flattening, corner sight distance improvements, and installation of traffic signals, among others. Reconstruction or realignment of the roadway is generally beyond the scope of a 3R project and, therefore, was not examined.

The specific objectives of NCHRP Project 17-9(2) were as follows:

- Identify the major categories of safety improvements implemented in conjunction with resurfacing of two-lane roads;
- Document the crash impact, relative to the conditions before the project, of (a) resurfacing without additional safety improvements and (b) resurfacing in conjunction with the safety improvements; and
- Present data comparing the pre-improvement and the post-improvement crash experience for the various improvement categories.

SCOPE OF STUDY AND RESEARCH APPROACH

The scope of this research was limited to two-lane roads with no control of access and posted speed limits equal to or greater than 45 mi/h (72 km/h) in rural and suburban areas.

The research started with a comprehensive literature review and a compilation of state practices related to resurfacing projects. The information regarding state practices was synthesized from information contained in *TRB Special Report 214* (Transportation Research Board, 1987), in selected reports published by three state agencies, and in a survey of state agencies conducted for this project report. In the next phase, statistical analysis was performed on data from five states to identify the impacts of improvements on safety after resurfacing.

LITERATURE REVIEW

A review of documented research related to the safety impacts of resurfacing projects was performed and is presented in Appendix A of the final report, which is available for loan upon request from the National Cooperative Highway Research Program. The overall finding from the review was that several studies reported a significant increase in crashes after resurfacing, several found no statistically significant increase, and at least one reported a decrease in crashes. Where a distinction was made between dry and wet pavement crashes, the majority of the analyses found an increase and decrease, respectively. This observation, however, was believed to depend highly on the frequency of wet pavement crashes during the before period. The effect on crashes was also found to vary depending on whether the location was urban or rural.

The apparent discrepancies among the studies may, in part, be due to methodological differences, as observed in *TRB State of the Art Report 6* (Cleveland, 1987). Although some of these studies can be criticized for the methodology employed in site selection and analysis, the random nature of the crash data, especially on rural, two-lane roads, makes definitive conclusions inherently difficult. Regression to the mean was a common concern when a small sample size or a short before-and-after period was used. Regression to the mean was also a concern when treatment sites had been selected for resurfacing primarily on the basis of crash history. Another possible explanation for the contradictory results could be the difference in scope of the various resurfacing projects. Depending on the state, a standard resurfacing project could vary from applying only a new surface course to making additional cross-section and roadside safety improvements.

Past studies provided valuable insight into the methodology formulated for this analysis. These conclusions are summarized as follows:

- Regression to the mean can be, to a certain degree, accounted for by means of one or more of the following: selection of sites slated for resurfacing on the basis of pavement condition alone, and not on the basis of crash history; use of a long crash history (i.e., 3–5 years); and use of a large sample size with respect to mileage of roadway.
- A reference group that accounts for other unknown accident trends should be employed to avoid false conclusions about the effect of the treatment.
- The crash analysis should be performed on a monthly basis because the safety effect is believed to be higher in the first 1–3 years after resurfacing.
- The crash analysis should segregate intersection and nonintersection crashes because resurfacing is believed to have a different effect on each.

STATE PRACTICES

A survey of state highway agencies was conducted to gather more detailed information on practices related to safety improvement and resurfacing. A survey was mailed to the division responsible for the design of 3R projects in each of the 50 states. A total of 36 agencies responded. Questions ranged from how the design standards or guidelines used for 3R projects differ from new construction standards, to how resurfacing projects are selected, to which specific safety improvements are most likely to be implemented with resurfacing projects.

The responses to the survey questions differed from state to state in various degrees. For example, most states (i.e., 32 of 36) responded that the guidelines used for 3R projects differ from the guidelines used for new construction projects. On the other hand, only 14 of 35 states indicated having a policy for conducting a cost-effectiveness analysis of alternative safety improvements associated with resurfacing projects considering construction cost versus crash potential.

It is very difficult to draw "inter-state" conclusions, because the practices differ from state to state. However, the results of this survey identified states that have the project and crash data necessary for this study. Also, the survey reports the states' willingness to participate in the study.

STATISTICAL ANALYSIS

This section describes the data collection and data analysis procedures, as well as the analysis results for each state.

Site Groups

The analysis performed for this study incorporated the insights gained from the literature review. Hence, three groups of data are used and referenced throughout the analysis and this digest:

- **Treatment group** sections were resurfaced between 1990 and 1993 and were selected for work because of their pavement condition. Each section was at least 0.5 mi (0.8 km) long. Sections treated with a bituminous surface treatment (BST) or "chip seal" were discarded. Conversely, reconstruction, capacity improvements, and realignment projects were removed from the list of candidate locations.
- **Reference group** sections consisted of roadway sections whose distribution of annual average daily traffic (AADT), urban and rural location, and functional class closely matched those of the treatment group. The roadways were not resurfaced during the analysis period.

The function of the reference group was to account for crash trends that could not be factored into the crash prediction equations, such as changes in enforcement and economic conditions. The desired reference group sample size was twice the size of the treatment group (as measured by mileage).

- **Downstream group** sections were adjacent to each treatment group section, as shown in Figure 1. Each downstream section was 1.0 mi (1.6 km) long. Advancing the hypothesis that speed increases on resurfaced sections, the researchers postulated that additional safety impacts might occur on roadway sections immediately downstream of the treated section. Thus, an accident increase might be observed at locations beyond the limits of the resurfaced pavement.

Roadway sections in all groups were restricted to a minimum AADT of 500 and were required to be noninterstate road sections having only two travel lanes. Table 1 shows the number of sites included in each group.

Data Collection

Data were collected in the states of Washington, California, New York, Minnesota, and Illinois. The same data were requested from each state, but there were small discrepancies in the types of files provided (i.e., electronic or paper), the exact information available from state to state (e.g., the years of accident data available), and the detail of information available (e.g., project costs categorized as lighting improvements and guardrail). The data were provided by the state departments of transportation or from FHWA's Highway Safety Information System (HSIS). The requested data included resurfacing project data, roadway data, traffic data, and accident data.

Resurfacing Project Data

These data were used to identify possible sites to be included in the treatment group. As noted in the criteria for treatment sites, the roadway sections were resurfaced be-

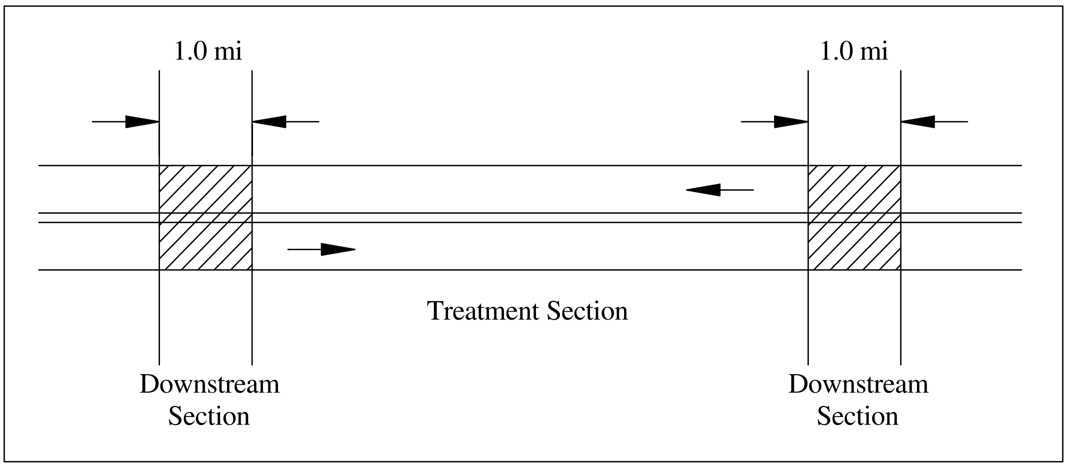

Figure 1. Treatment and downstream sections.

TABLE 1 Sites included in treatment, reference, and downstream groups

State	Treatment Group		Reference Group		Downstream Group	
	Number of Sites	Total Miles	Number of Sites	Total Miles	Number of Sites	Total Miles
Washington	46	254.05	118	445.42	65	65.00
California	53	182.10	116	354.63	85	84.60
Minnesota	43	445.55	155	1183.67	N/A	
New York	50	259.04	124	259.74	70	70.00
Illinois	58	384.60	596	885.21	49	49.00

tween 1990 and 1993. After sites were selected as part of the treatment group on the basis of other criteria mentioned previously, the sites were categorized according to the resurfacing work: resurfacing only, minor safety improvements, and major safety improvements. However, the definition of the improvement as a minor or major safety improvement should be viewed cautiously.

The methodology used to determine minor and major improvements varies from state to state, and the definition of major and minor improvements was based on the information recorded and available to the researchers. For example, in Washington and New York, a safety percentage was used to define minor and major improvements. A safety percentage is the total dollars expended on specific safety improvements (such as guardrail, removal of roadside objects, and lighting) divided by the total project cost. Such detailed cost information was not available for every state, and so major and minor improvements were defined using the information available (e.g., project description, cost per mile, and design standards).

Roadway Data

These data were used to further identify sites to be included in the reference group. The mileage distribution of the reference group sites closely matched that of the treatment and downstream sites. Sites were eliminated that did not fall within the boundaries of the treatment group. For example, roadways with a surface width of 18 ft (5.5 m) or less would be eliminated if there were no sections in the treatment group less than 20 ft (6.1 m) wide.

Traffic Data

For all three data groups, traffic volumes for multiple years were obtained. Weighted averages were computed when more than one volume was listed for a site. For downstream section sites, treatment AADT volumes were used because of the sites' proximity to the test sites. A computer program was used to interpolate AADT for the years in which AADT was not provided.

Crash Data

Crash data, summarized by month and year, for each site in the treatment and reference data groups were obtained. Additionally, the crash data were separated into four crash types: total intersection crashes, total segment crashes, injury intersection crashes, and injury segment crashes. For this analysis, segment crashes are nonintersection crashes, and injury crashes include both injuries and fatalities. Illinois was an exception, however, and its intersection and segment crashes could not be separated because there was no variable defining such a location. For most states and sites, the "before" period was 5 years and the "after" period was 3 years.

For the downstream sites, crashes were classified differently. Accidents were categorized by direction of travel relative to the resurfaced section: those with at least one vehicle leaving (i.e., traveling away from the resurfaced section) and those with at least one vehicle entering (i.e., traveling toward the resurfaced section). Thus, the four categories are all entering, all leaving, injury entering, and injury leaving. For Minnesota, the analysis of downstream sections was omitted because the vehicle direction of travel could not be determined from the data.

Data Analysis Techniques

The most widely accepted analysis procedure to establish with statistical confidence whether a highway treatment has been effective in reducing crashes is to employ the reference comparison analysis technique. Simply comparing the number of crashes that occurred before and after a treatment to determine the affect can lead to an incorrect conclusion. This situation can occur because of the regression-to-the-mean phenomenon that happens with crash occurrence. Because of their randomness, the number of crashes will change each year for no other reason than their likelihood of occurring. Therefore, any change that is determined from a simple before-and-after comparison is likely inaccurate and, therefore, inconclusive.

A procedure to overcome this situation is to employ a reference comparison analysis. In this case, a sample of reference and treatment sites is selected. The reference sites are those that did not receive any change during the study period. These sites should be similar with respect to those features that are likely to affect crash occurrence (e.g., volume, lane widths, shoulder widths, and roadside features).

The data from the reference group are used to develop a crash prediction model using appropriate statistical procedures. The estimation of the safety level without treatment is based on information from the reference group model and on the actual "before" data for the treatment sites. This best-proven procedure is the empirical Bayes procedure, which provides an additional way to guard against regression-to-mean bias.

The model derived from these two sources of information is then used to predict the accident occurrence at the treatment site in the "after" period. The predicted number of accidents in the "after" period is then compared with the actual (i.e., observed) number of accidents in the "after" period to determine the effect of resurfacing.

Data Analysis Procedures

Empirical Bayes statistical analysis procedures were employed to address biases due to regression to the mean. The data from each state were analyzed independently (i.e., crash prediction models were developed for each state using only that state's data). A five-step data analysis procedure was performed:

1. Conduct an exploratory analysis of reference group data,
2. Develop models that estimate safety performance,
3. Analyze reference group data by monthly variation,
4. Analyze treatment group data, and
5. Analyze downstream data.

The specific approach associated with each of the five tasks is defined in the following sections.

Step 1: Conduct an Exploratory Analysis of Reference Group Data

The purpose of the exploratory analysis is to identify the proper functional form for how the crash frequency depends on AADT for the reference group sites. A separate analysis was performed for total intersection crashes, total segment crashes, injury intersection crashes, and injury segment crashes. For each analysis, the traffic from the reference group site was sorted into groups of 100 vehicles according to AADT (e.g., 1,000–1,099, 1,100–1,199, and so forth), and the number of crashes per intersection per year (or crashes per mile per year) was calculated. The relationship was then charted on a scatter plot. Additional insight into the proper functional form was gained by plotting the empirical integral function (EIF) and the log-log transformation of the curve. The most common forms identified include the power function $\left(f(\mathrm{AADT}) \propto \mathrm{AADT}^{\beta}\right)$, the Hoerl function $\left(f(\mathrm{AADT}) \propto \mathrm{AADT}^{\beta_1} e^{\beta_2 \times \mathrm{AADT}}\right)$, and the polynomial function $\left(f(\mathrm{AADT}) \propto \mathrm{AADT} + \beta_1 \mathrm{AADT}^2 + \ldots\right)$. After comparing the various models using only AADT as the independent variable, functions were identified to further test additional variables, as discussed in Step 2.

The analysis also included a sensitivity test to determine if the rural or urban variable was critical in identifying the proper model form. However, the results of doing the previous analysis with the rural and urban sites separate revealed no distinction between the two groups in terms of the crash frequencies or their EIF. Thus, the rural and urban groups can be analyzed jointly at this initial stage.

Step 2: Develop Models That Estimate Safety Performance

The goal of model development is to use the reference group to estimate what the safety performance of the treated sites would be had no improvements been made. In Step 1, preliminary model investigation considered only the AADT. In Step 2, additional variables were considered, including urban or rural location, pavement width, shoulder width, terrain, and functional class. The model took the classic form of a crash prediction equation:

$$\text{Crash Rate} = f(\text{AADT, shoulder width, pavement width, terrain, etc.})$$

Crash prediction equations were created for each crash type: total intersection crashes, fatal and injury intersection crashes, total segment crashes, and fatal and injury segment crashes. Variables were added to the equation if they improved the model, as quantified by the log likelihood factor. Table 2 summarizes the variables included in the different models. For Illinois, no distinction could be made between intersection and segment crashes. This lack of distinction complicates model building because road sections differ in both length and number of intersections. Thus, the equations used to develop the models were slightly different for the Illinois data.

Step 3: Analyze Reference Group Data by Monthly Variation

The effect of resurfacing on safety was estimated as a function of the number of months after the end of construction. This analysis involved creating tables with the number of crashes per month for the reference group. Preparing the data in such a way was necessary for the calculations in the next step. These calculations require the crashes at each site to be separated into months.

Step 4: Analyze Treatment Group Data

This analysis of the treatment sites involved comparing the effects of resurfacing improvements on safety. The treatment sites include road sections that were only resurfaced and also road sections that both were resurfaced and had additional safety improvements. The analysis was accomplished by calculating the expected number of crashes for the treated site when no improvements were made and comparing these values with the actual number of crashes for the site after the treatment was performed.

For each treated site, the number of crashes predicted to occur for each month was calculated. This calculation used the models developed in Step 2 and the reference sites. The site-specific parameters for the treatment sites were entered into the regression model. This entering produced an estimate of safety for the "before" period if the site's crash experience was like that of the reference group. Finally, the actual "before" crash experience was combined with these regression outputs in a weighted fashion to develop the estimated "true" level of safety in the "before" period for each site.

The next task in this step is to predict what safety would have been in the "after" period had the site not been resurfaced. Changes in AADT and year-to-year variation are accounted for using the model equation and its parameters, and the monthly variation is accounted for using monthly multipliers. The monthly predicted crashes were computed for all the treatment roadway sections.

The before-and-after comparison evaluates the difference between the *predicted* "after" number of crashes for all the sites, as calculated previously, and the *actual* number of

TABLE 2 Variables included in crash prediction models

State	Total Segment	Injury Segment	Total Intersection	Injury Intersection
Washington	Urban/Rural Pavement width Shoulder width	Urban/Rural Pavement width Shoulder width	Urban/Rural Pavement width Shoulder width	Pavement width Shoulder width
California	Urban/Rural Terrain Pavement width	Urban/Rural Terrain Pavement width	Urban/Rural Terrain	Urban/Rural Terrain
Minnesota	Functional class Shoulder width	Functional class Shoulder width	Functional class Shoulder width	Functional class Shoulder width
New York	Urban/Rural Functional class Pavement width Shoulder width	Urban/Rural Functional class Pavement width Shoulder width	Urban/Rural Functional class Pavement width Shoulder width	Urban/Rural Functional class Pavement width Shoulder width
Illinois	Total Crashes:	Urban/Rural Functional class Pavement width Shoulder width	Injury Crashes:	Urban/Rural Functional class Pavement width Shoulder width

"after" crashes that occurred. In this analysis, both the resurfacing-only sites and the resurfaced sites with additional improvements were analyzed together. No distinction can be made from these results regarding the effects of the additional safety improvements at resurfaced locations. The percentage change between these two values for each state and each category is listed in Table 3. (Remember that, because of data limitations, Illinois data could not be separated into intersection and segment crashes.)

A *positive* value indicates that the predicted number of crashes is greater than observed, meaning a decrease in crashes and a possible conclusion that resurfacing positively affects safety.

A *negative* value indicates that the predicted number of crashes is less than observed, meaning an increase in crashes and a possible conclusion that resurfacing negatively affects safety.

To interpret this table, the following examples are provided. Washington has the greatest positive reduction for all of the categories, indicating that resurfacing appears to reduce the number of crashes occurring on the treatment roadway sections. The results for Minnesota are opposite, indicating that resurfacing appears to increase the number of crashes. California, New York, and Illinois all have varying results.

Because the number of crashes predicted to occur were calculated for each month, the effect of resurfacing over time was investigated. The plot of monthly cumulative crash savings versus cumulative crash projections revealed much about the impact of resurfacing over time. For Washington, the safety of the segment crashes (both total and injury only) increased as the pavement aged, while the intersection crashes (both total and injury only) showed a consistent crash savings over the 3 years analyzed. Although Minnesota has an apparent increase in crashes, the safety of the sites improves as the pavement ages because the magnitude of the increase in crashes is reduced (e.g., from 33 percent to 12 percent). The remaining three sites have mixed conclusions, including statistically insignificant results, a consistent increase in crashes after resurfacing, or no change in the number of crashes.

Step 5: Analyze Downstream Data

As stated previously, by advancing the hypothesis that speed increases on resurfaced sections, the researchers postulated that additional safety impacts might occur on roadway sections immediately downstream of the treated section. Thus, a crash increase might be observed at locations beyond the limits of the resurfaced pavement. The methodology for the downstream data analysis follows the same approach as that for the treatment group. Crash rates were predicted for the "after" period using the models developed from the reference data (the sites should be similar). The predicted values were then compared with the number of reported crashes to quantify the safety impacts of resurfacing on roadway sections immediately downstream of the treated section.

In all the states except Minnesota (where downstream analysis was not possible), the analysis yielded no evidence

TABLE 3 Results of empirical Bayes analysis

Crash Category	Percent Reduction (predicted-observed)				
	Washington	California	Minnesota	New York	Illinois
Total Intersection	18.4	-0.4	-26.5	-34.4	--
Injury Intersection	17.6	1.4	-30.7	-51.0	--
Total Segment	14.3	-7.2	-14.8	1.6	--
Injury Segment	21.6	-2.0	-27.4	3.2	--
Total (Intersection and Segment)	--	--	--	--	-3.0
Injury (Intersection and Segment)	--	--	--	--	-0.6

to suggest that resurfacing adversely affected crash frequency downstream of the resurfaced road section. However, remember that the original intention was to distinguish between crashes involving vehicles that just left the newly resurfaced road and crashes with vehicles not exposed to travel on the new blacktop. This distinction is not fully present in the crash categories created (i.e., entering and leaving). Crashes involving vehicles traveling in opposite directions involve vehicles of both kinds, entering and leaving, and are included in more than one category. Thus, the intended distinction has been achieved only partly.

Analysis Findings

Appendixes B, C, D, E, and F of the final report, which are available for loan upon request from the National Cooperative Highway Research Program, completely document the data and analyses for each state. The primary finding from these appendixes has been summarized previously. For example, Table 3 summarizes the results of the empirical Bayes analysis with reference group analysis. This table shows an inconsistency in the quantifiable results from state to state and even between the different crash groups (i.e., total or injury crashes, segment or intersection crashes). Thus, it is difficult to draw summary conclusions regarding the effects of resurfacing from these analysis results. Additionally, as mentioned previously, there does not seem to be any statistical evidence to support the hypothesis that resurfacing adversely affects crash frequency at sites downstream of the resurfaced road section.

Nevertheless, these results provide the basis for further investigation of the effects of resurfacing with and without additional safety improvements. The empirical Bayes analysis results show that resurfacing seems to positively affect Washington, because all crash categories experience fewer actual crashes in the "after" period than what the model had predicted. On the other hand, the analysis for Minnesota shows that, in all crash categories, more crashes actually occurred than what was predicted for the "after" period.

SAFETY EFFECT OF RESURFACING AND IMPROVEMENTS

The previous results are for all roadway sections, including those that were resurfaced only and those with additional safety improvements. However, the main issue to address with this research and analysis was the crash impact of resurfacing two-lane roads with and without additional safety improvements. Because of budget constraints, further investigation was limited to only some of the states. The results from the empirical Bayes analysis show consistency between crash groups from Washington and Minnesota and yet contrasting outcomes from these same states. Hence, these two states were selected for further analysis.

The analysis in this section is simplified as compared with the empirical Bayes procedure using reference groups. For this analysis, the difference between the "before" and "after" crash rates is of interest. This procedure does not have any control over the regression-to-the-mean bias or various other biases. However, the procedure is a simplified method to investigate the crash impact of resurfacing with and without additional safety improvements, and the resulting conclusions will be limited to points not statistically proven but suggested by the data. For this analysis, only the data for total segment crashes were used.

When describing the resurfacing project data required for this study, the researchers divided resurfacing and safety improvements into three categories (resurfacing only, minor improvements, major improvements). For Washington, this division was done using the safety percentage (i.e., the total dollars expended on safety improvements divided by the total project cost). For Minnesota, projects were classified more qualitatively using the project plans, quantity information, project description, design standards, and cost per mile. Because two different methodologies were used to classify minor and major safety improvements in Washington and Minnesota, the minor and major improvement groups from these states cannot be compared. Hence, the sites for the following analysis discussion are classified as resurfacing only or resurfacing with an additional safety improvement. Table 4 indicates the number of sites in these two categories.

For each site, the number of total segment crashes occurring in the 36 months prior to construction and the 36 months after construction were summed. These totals were then calculated as rates (i.e., the number of crashes per year per mile). The differences in these rates are plotted in Figures 2 and 3. As with the empirical Bayes analysis, the differences are reported as a percent reduction; hence, a *positive* difference indicates that there were *fewer crashes* in the "after" period, possibly a *positive effect* of resurfacing only or resurfacing with additional safety improvements. On the other hand, a *negative* difference indicates *more* crashes in the "after" period, perhaps signifying a *negative effect* of resurfacing only or resurfacing with additional safety improvements.

One of the first things to notice in Figures 2 and 3 is the magnitude of the difference value. The rate differences for Minnesota is between -1.0 and 1.0. On the other hand, eight of the rate differences for the Washington sites (i.e., 8 of 46, or 17 percent) are beyond the 1.0 to -1.0 range. Site characteristics will be investigated to determine whether attributes stand out as being a factor for these differences. First, however, the number of sites with the various differences is investigated.

Table 5 summarizes the number of sites that have a positive rate reduction, the number of sites that have a negative rate reduction, and the number of sites that have no change. In Washington, adding safety improvements to resurfacing work did not seem to reduce crashes. In fact, a higher percentage of sites experienced more crashes in the "after" period when resurfacing was coupled with other improvements (i.e., 40 percent to 48 percent). The biggest change for Washington is the percentage of sites experiencing more crashes in the "before" period (i.e., experiencing a positive reduction). This percentage drops from 60 percent to 42 percent, indicating that, among sites that experienced both resurfacing and other improvements, fewer sites experienced more crashes in the "before" period (i.e., more sites experienced more crashes in the "after" period). Thus, data from Washington indicated that resurfacing with some additional improvement does not seem to decrease the number of crashes.

The explanation of Minnesota is different. The percentage of sites with a positive rate reduction increases when additional improvements are made to the resurfacing. This increase means that when other safety features are added, the number of sites with more crashes in the "after" period (as compared with the "before" period) decreases. On the other hand, the percentage of sites with a negative reduction decreases when additional improvements are made to resurfacing, meaning that fewer sites have more crashes in the "after" period (as compared with the "before" period) when additional improvements are made along with resurfacing. These changes in the percent differences in Minnesota seem to indicate that resurfacing with some additional improvement does, indeed, reduce the number of crashes.

When comparing the data between states, notice that for the sites with some additional safety improvement, the percentages of sites having the various reductions are similar.

It is important not only to investigate the numerical differences at the sites, but also to look at the specific characteristics of a site and see whether any characteristic seems to be the indicator for an extreme site. For instance, did the sites that were resurfaced with some other improvement also change from a lane width of 10 ft before resurfacing to a lane width of 12 ft after resurfacing? Additionally, the state itself may influence the difference. Does the design practice of a state or the thresholds established for a state differ and, therefore, influence the crash rate? What about the effect of reporting practices or even the climate of the state? How do these attributes affect the safety of resurfacing with and without additional safety improvements?

Tables 6 and 7 list the extreme rate differences for Washington and Minnesota, respectively. A rate difference above 0.5 is defined as extreme. The most obvious fact that stands out from these tables is the number of sites in the Washington data with resurfacing and other improvements with a positive or negative rate reduction above 0.5. For all other groups (including Washington resurfacing only and both Minnesota groups), there are, at most, two sites with "extreme" differences. However, for the Washington sites

TABLE 4 Sites in Washington and Minnesota

State	Total	Resurfacing Only	Some Safety Improvements
Washington	46	15	31
Minnesota	43	16	27

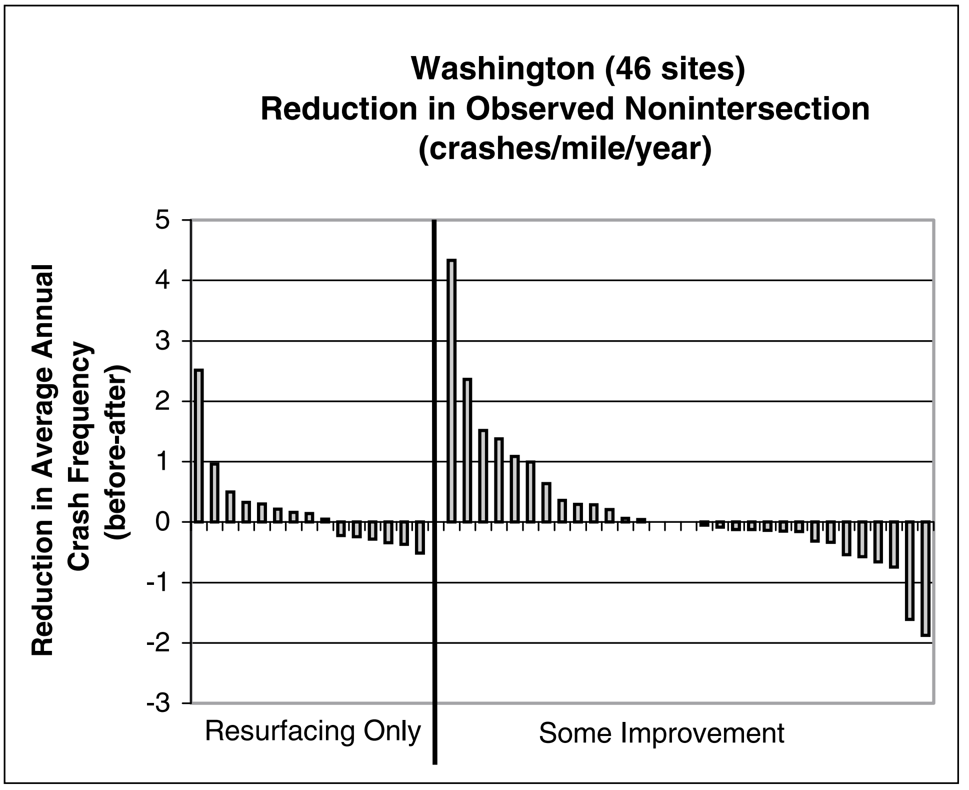

Figure 2. Reduction in average annual crash frequency for Washington.

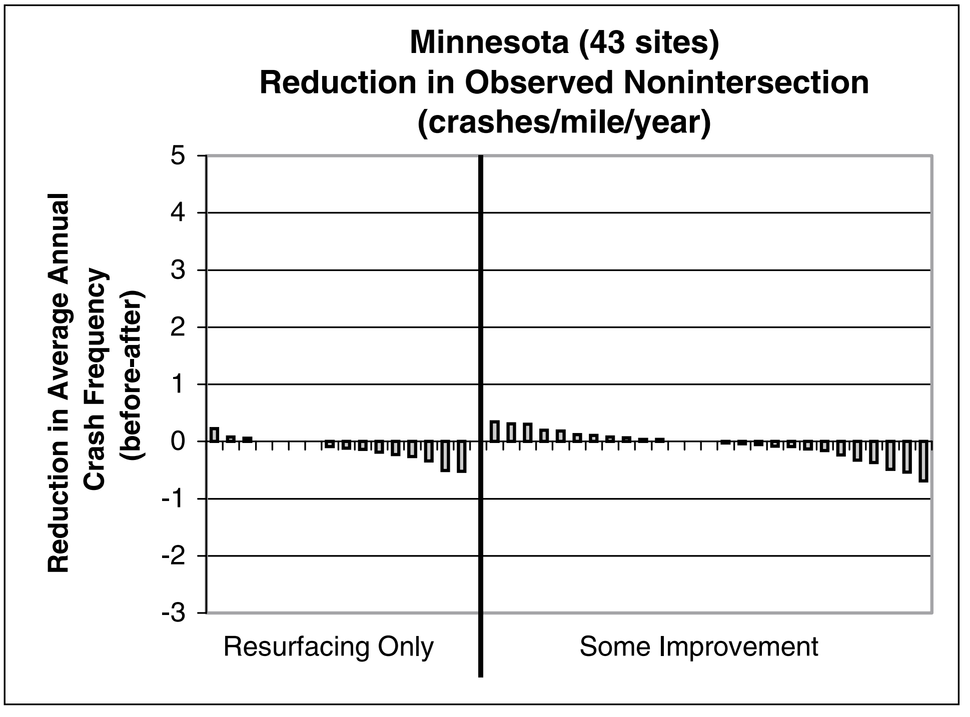

Figure 3. Reduction in average annual crash frequency for Minnesota.

TABLE 5 Categorization of sites and rate reduction

Segment Category	Reduction (before-after)	Number of Sites (%) Washington	Minnesota
Resurfacing only	Positive reduction	9 (60%)	3 (19%)
	No change	0	4 (25%)
	Negative reduction	6 (40%)	9 (56%)
Some Improvement	Positive reduction	13 (42%)	11 (41%)
	No change	3 (10%)	3 (11%)
	Negative reduction	15 (48%)	13 (48%)

with resurfacing and other improvements, 13 sites are defined as extreme. Is there a similar identifiable attribute among these sites that makes the positive or negative reduction “extreme”? In general, are there identifiable attributes of the “extreme” sites that lead to these differences in crash rates?

A qualitative analysis compared the different traits of the various sites to see whether there was an identifiable consistency or difference in site characteristics of the extreme sites. However, even with the descriptive information available, no site characteristic seemed to be an indicator of a higher than average or lower than average rate difference.

TABLE 6 Extreme rate differences for Washington

Resurfacing Only		Resurfacing and Other Improvements	
Site Number	**Reduction**	**Site Number**	**Difference**
42	-0.51	65	-1.87
		106	-1.61
		109	-0.75
		107	-0.66
		58	-0.58
		96	-0.54
153	0.96	72	0.64
166	2.51	2	0.99
		50	1.08
		122	1.38
		144	1.52
		79	2.36
		111	4.33

Note: an extreme rate difference is a rate difference above 0.5.

TABLE 7 Extreme rate differences for Minnesota

Resurfacing Only		Resurfacing and Other Improvements	
Site Number	**Difference**	**Site Number**	**Difference**
38	-0.52	34	-0.69
54	-0.51	36	-0.54
No positive reduction greater than 0.5		No positive reduction greater than 0.5	

Note: an extreme rate difference is a rate difference above 0.5.

This lack of identifiable indicators does not mean that no indicator (or group of indicators) exists, but only that none were identifiable in the information available to the researchers.

The difference between the results of Washington and Minnesota may relate to items beyond individual site characteristics. For instance, what is the difference between Washington and Minnesota that causes the value of the average rate difference to be greater for Washington? The answer may have something to do with state resurfacing practices, state reporting thresholds for crashes, or state definitions of additional safety improvements.

SUMMARY OF STATISTICAL ANALYSIS RESULTS

The results from the empirical Bayes analysis show a great variation among states and crashes groups (i.e., injury or total crashes, intersection or segment crashes) regarding the influence of resurfacing on the crash rate. However, Minnesota and Washington were consistent within themselves while contrasting with each other. Resurfacing roads in Minnesota seemed to increase the number of crashes, while resurfacing roads in Washington seemed to decrease the number of crashes.

The effect of resurfacing with and without additional safety improvements was investigated through a before-and-after comparison of crash rates. In the Washington data, the percent reductions indicate that adding additional safety improvements to resurfacing does not add an additional safety improvement. However, in Minnesota, the opposite is true, and resurfacing plus some other safety improvement does seem to give an additional safety benefit.

The magnitude of the reductions is much bigger for Washington as compared with Minnesota. Thus, although additional safety improvements seem to decrease the crash rate in Minnesota, the magnitude of the difference is quite small.

CONCLUSIONS

There were three main conclusions of this research:

- According to the literature reviewed and the results of the data analysis, the effect of resurfacing a roadway clearly differs within and among the states because of the difference in individual site characteristics. In the information available to the researchers, there was no consistent pattern to explain this difference. There were also differences in the effect of resurfacing with and without additional safety improvements across the states that were analyzed. For Minnesota, the results suggest a negative safety effect of resurfacing. For Washington, the results suggest that there is not necessarily a negative safety effect of resurfacing. In the other states, the results were mixed. It is emphasized that the results are greatly limited by the quality and quantity of the data.

  Engineering intuition indicates that there must be some key differences from site to site that will affect the safety of the site. Such differences may include roadway geometry and roadside environment. The difference may also be with the design practice of the state. However, such characteristics were not available or described in the information obtained by the researchers.

- According to previous research, roadway resurfacing seems to have a novelty effect, meaning that the effect of some new installation or improvement wears off over time. Initially after resurfacing, more crashes may occur on the roadway section because of drivers' perception of increased safety. However, over time, the perception of newness of roadway wears off, and the number of crashes "returns to the average." For the first 6–7 years of pavement life, safety improves as the pavement ages (Hauer, Terry, and Griffith; 1994).

As stated in the first conclusion, the result from state to state is inconsistent, and the same is true with respect to the effect of resurfacing over time. For Washington, there was a statistically significant reduction in crashes for the first year after resurfacing, followed by a more sharp reduction for the following 2 years. In Minnesota, there was a statistically significant increase in crashes that was large initially and then diminished. Hence, these states support the earlier research conclusion that safety improves as the pavement ages. However, the remaining three states analyzed for this study do not follow that same trend, although they do not counter the claim, either. The results of these remaining states include statistically insignificant changes, no change in crash occurrence, or consistent increases in the number of crashes.

The states that support previous research conclusions regarding the novelty effect are the same states that show (a) a significant change in the number of crashes due to resurfacing and other safety improvements, (b) consistency between the analysis results for the different crash groups, and (c) contrast in results with one another. These states (i.e., the states that support previous research conclusions about the novelty effect) are the best results for indicating trends. Although not all the results from each state analyzed indicate a consistent effect over time, the two states with the most promising results (i.e., Washington and Minnesota) indicated that safety improves as pavement ages.

- The investigation of the effect of resurfacing roads was extended to investigating the road downstream of the newly resurfaced road sections. Three methodologies were used, including a comparison of the average monthly crashes on the downstream section before and after resurfacing, an investigation of whether an adverse effect of resurfacing is discernible close to the time of resurfacing (i.e., whether there was a cumulative crash difference), and a comparison that accounts for changes in traffic flow and for the monthly variation. Data were collected for 269 1-mi sections adjacent to the treatment sites in each of the five states. The empirical Bayes methodology was used for analysis of the downstream sections in each state individually, and the results yielded no evidence to suggest that resurfacing adversely affects crash frequency downstream of the resurfaced road sections.

RECOMMENDATIONS

The results of this research effort make it difficult to clearly identify the conditions when specific types of safety improvements need to be implemented in conjunction with road resurfacing projects. In fact, from the analysis in this study, it is difficult to even conclude that resurfacing does, indeed, increase the number of reported crashes or that adding safety improvements to the roadway will prevent such an increase. The researchers hypothesize that individual site characteristics and perhaps resurfacing practices affect crash occurrence immediately after resurfacing. The researchers could assemble only limited data for a limited number of sites and could not investigate the differences in resurfacing practices because of constraints in available resources.

The analysis of the data, unfortunately, did not reveal strong relationships between crash occurrence after resurfacing and pre-resurfacing pavement conditions, geometric conditions, or aspects of the resurfacing project. Furthermore, the effect of specific safety improvements on the relative change in crash experience could not be developed. The availability and accuracy of data were limiting constraints. A more promising methodology for this type of study would employ a before-and-after comparison with randomized controls. The researchers recommend that this approach be pursued using a much more limited sample of sites in one or, at most, two states as part of a multistate pooled fund study. With greater controls over the site conditions and treatment site selection, it is hoped that more definite relationships can be developed.

FINAL REPORT AVAILABILITY

The agency's final report, which was distributed to NCHRP sponsors (i.e., the state departments of transportation), is available for loan on request to the National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, NW, Washington, D.C. 20418.

REFERENCES

E. Hauer, D. Terry and M. S. Griffith, "Effect of Resurfacing on Safety of Two-Lane Rural Roads in New York State," *Transportation Research Record 1467,* Transportation Research Board, National Research Council, Washington, D.C., 1994.

H. W. McGee, W. E. Hughes, and K. Daily, "Effect of Highway Standards on Safety," *NCHRP Report 374,* Transportation Research Board, National Research Council, Washington, D.C., 1995.

Transportation Research Board, "Designing Safer Roads: Practices for Resurfacing, Restoration, and Rehabilitation," *TRB Special Report 214,* National Research Council, Washington, D.C., 1987.

D. E. Cleveland, "Effect of Resurfacing on Highway Safety," *TRB State of the Art Report 6,* Transportation Research Board, National Research Council, Washington, D.C., 1987.

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