# Effect of Resurfacing on Safety of Two-Lane Rural Roads in New York State

EZRA HAUER, DONALD TERRY, AND MICHAEL S. GRIFFITH

In the early 1980s, two kinds of resurfacing projects were undertaken in New York State: Fast track projects involving only resurfacing and reconditioning and preservation (R&P) projects in which roadside and roadway safety improvements have been incorporated with resurfacing. The question was whether following resurfacing the fast track projects (226.7 mi) perform less well, from a safety viewpoint, than the R&P projects (137.2 mi). Findings indicated that in fast track projects safety initially declined, but in R&P projects safety improved. Another conclusion that emerges from this work is that, within the first 6 to 7 years of pavement life, safety improves as the pavement ages. The Empirical Bayes approach to the study of the safety effect has been used. Two methodological innovations may be of interest. First, because the safety effect of resurfacing changes as the pavement ages, it was necessary to find a way to examine changes in safety as a function of time. Second, the accuracy of studies of this kind is often limited by the sparsity of accident data. The method used here allows the use of a long "before" accident history to enhance estimation accuracy.

The effect of resurfacing on the safety of rural two-lane roads was in the eye of a stormy debate in the late 1980s. To clarify the issue, a special TRB study was initiated, culminating in the publication of *Designing Safer Roads* (*1*). A critical review of published evidence conducted for this study by Cleveland (*2*) concluded that, although there is diversity in the findings of the few extant studies, the detrimental effect of resurfacing on safety, if any, is likely to be small.

In the State of New York Department of Transportation (NYDOT) as in all states, road resurfacing is an ongoing activity. In the early 1980s, two kinds of resurfacing projects were undertaken.

- Projects involving only resurfacing are called fast track. These consist of simple resurfacing and restriping. Initially, they did not include shoulder preparation or backing up, replacing guardrail, cutting trees, or other work. These activities were to be done later by the maintenance forces. After a few years, the scope of the fast track projects was enlarged to allow maintenance to catch up.
- Projects in which roadside and roadway safety improvements have been incorporated with resurfacing are called Reconditioning and Preservation (R&P) projects. In addition to resurfacing these may include limited pavement reconstruction and remedies to safety or operational problems. Superelevation, shoulder, drainage, slope flattening, and guide-rail and roadside improvements (removing or relocating fixed objects) are typically included.

E. Hauer, Department of Civil Engineering, University of Toronto, Toronto, Ontario M5S 1A4, Canada. D. Terry, Traffic Engineering and Safety Division, State of New York Department of Transportation, Albany, N.Y. 12232. M.S. Griffith, Office of Safety and Traffic, FHWA, 6300 Georgetown Pike, McLean, Va. 22101.

A before-and-after comparison indicated that there might be a substantial difference between the safety performance of these two kinds of resurfacing projects. To check whether the difference is real, additional data were collected for comparison sites. However, questions still remained about the appropriateness of the comparison groups selected, about a possible regression-to-mean bias, and about the statistical significance of the results. Eventually, the FHWA was asked to assist in resolving the issue whether projects involving only simple resurfacing perform less well, from a safety viewpoint, than similar resurfacing projects where roadside and roadway safety improvements have been incorporated.

This paper is the product of that request. The main aim is to add what has been found for the kinds of treatments used in New York state in the early 1980s to the store of facts about the safety effect of resurfacing. In performing the work, some methodological innovation was required and will be described without burdening the exposition with too much theory. Full details are given in the original report (*3*).

## DATA

All data pertain to rural, two-lane, undivided, free-access road sections. The following information has been assembled by officials of NYDOT for each road section:

- The length of the section and the number of intersections in it.
- Traffic counts for the 13 years from 1975 to 1987, factored to represent the AADT in the year of the count.
- The count of fatal, injury, property damage only, fixed object, and intersection accidents for each month of the 13 years from 1975 to 1987.
- If the road section was resurfaced, the month and year in which construction started and ended (mostly in the 1981 and 1982 construction seasons).

The data pertain to 82 fast track projects (226.7 mi, 2.09 intersection/mi), 55 R&P projects (137.2 mi, 4.36 intersections/mi), and 525 comparison and reference road sections (2193.2 mi with 1.92 intersections/mi). During preliminary analysis, a few suspicious traffic volumes, intersection densities, and accident records were identified. Where possible, these were checked and corrected. If verification or correction was not feasible, the data were not used.

## PRELIMINARIES

Before analysis could begin, several preparatory activities had to be undertaken.

## Estimating AADT

Because traffic and accidents are closely related, changes in traffic have to be accounted for when changes in safety are examined. The accident data to be analyzed are for the 13-year period from 1975 to 1987. Thus, estimates of AADT for the same period were needed.

Traffic counts are conducted on each road section every few years. These counts are then factored to represent the AADT in the year of the count. The task was to fill in all the blanks for the years for which there were no counts. This estimation procedure is described in detail in Appendix A of the work by Hauer (*3*). At the conclusion of this task, estimates of the AADT and its standard deviation for all 13 years for each of the 662 sites were obtained.

## Accident Counts

The following questions required answers:

1. What were the effects of changes in 1978 and again in 1985 in the reporting threshold for property damage only accidents?
2. What was the effect of the change that occurred in May 1993 in the definition of an intersection accident?
3. Is the year-to-year variation the same for all accident types to be analyzed?
4. What is the month-to-month variation by accident type?

In response to Questions 1 and 2, no discernible effect could be found for either the changes in the reporting threshold or the definition of what constitutes an intersection accident (*3*). On Question 3, each accident type was found to have its own year-to-year variation. Therefore, when modeling how the expected number of accidents depends on time and traffic, discrete parameters have to be assigned to each year and accident type.

Inasmuch as the safety effect will be estimated as a function of the number of months after the end of construction, information about month-to-month variation is also needed and has been estimated.

## Examination of Comparison and Reference Group

In before-and-after studies, the role of a comparison group is to account for changes in safety from the before to the after period that are due to a variety of uncontrolled factors (weather, accident-reporting threshold, driver demography, vehicle fleet, definition of intersection accident, etc.). Therefore, the requirement is that the change in these uncontrolled factors and their effects on safety be the same on the entities in the comparison group and on the treated entities. (Note that here the comparison group is not used to account for changes in traffic flow inasmuch as this can be done better using the available estimates of the AADT.)

A reference group in before-and-after studies serves mainly to account for any bias due to regression to the mean. The requirement is that the expected number of accidents of a treated entity with given traits (geometry, traffic flow) be the same, roughly, as the expected number of accidents of a reference-group entity with identical traits. Although the purpose and use of the comparison group and the reference groups are different, there is no reason why the same group of entities can not serve in both roles, provided that both requirements are met.

It was established earlier that one of the differences among the fast track, R&P, and the comparison and reference road sections was that their intersection densities are very different (2.09, 4.36, and 1.92 intersections/mi, respectively). It was therefore clear that intersection and nonintersection accidents have to be modeled separately.

The 525 road sections which make up the reference and comparison group are composed of 47 sections originally selected for their proximity to fast track projects, 49 sections originally selected for their proximity to R&P projects, and 429 sections selected to represent the entire state. Therefore, the comparison group requirement is likely to be satisfied. To examine the suitability of these road sections as a reference group, nonintersection accidents per vehicle-mi and intersection accidents per intersection-vehicle of treated and not-treated road sections were compared in the 1975 to 1980 period (i.e., before any construction took place). On the basis of such comparisons and in view of the overall similarity in the average rate and its large year-to-year fluctuations, it was concluded that there was no reason to distinguish between the three groups of road sections. Therefore, they were used jointly as one reference group.

In summary, the fast track sites differ from the R&P sites in intersection density. This required modeling intersection and nonintersection accidents separately. Once this was done, all untreated sites were combined to serve as reference group and as comparison group.

## Multivariate Modeling

To account for the effect of changes in uncontrolled factors (weather, reporting threshold, demography, etc.), for the effect of changes in AADT, and also for the possible bias due to regression to mean, the parameters of a set of multivariate models need to be estimated. These models link accident counts from 1975 to 1987 to traffic in those years and to variables representing the passage of time. (Details are given in Hauer (*3*), Appendix D). Three models were estimated for three accident types: (a) nonintersection accidents, (b) intersection accidents, and (c) fixed-object accidents.

The models are of the form

$$E(m_{i,y}) = \alpha_y F_{i,y}^{\beta}$$
$$\text{VAR}(m_{i,y}) = [E(m_{i,y})]^2/b \qquad (1)$$

where

$m_{i,y}$ = what would be the average number of accidents per mi (or per intersection) of road section $i$ in year $y$ if it were possible to freeze all relevant conditions of year $y$ and repeat them a very large number of times. If there were another road section $j$, with the same traffic as section $i$, in the same state, same number of lanes, and so forth, still $m_{i,y} \neq m_{j,y}$ because the two road sections will differ in many traits that are unmeasured and are not featured in the model.

$E(m_{i,y})$ = average of the $m_{i,y}$'s for an imaginary set of road sections that have exactly the same measured and modeled traits (including traffic) as section $i$.

$\text{VAR}(m_{i,y})$ = variance of these $m_{i,y}$'s.

$\alpha_y$ = parameter for year $y$ that captures the influence of all factors that change from year to year, except for the change in traffic flow. Values are estimated for $\alpha_1, \alpha_2, \ldots, \alpha_{13}$, in which the subscript 1 is for 1975, 2 for 1976, ..., 13 for 1987.

$F_{i,y}$ = AADT for road section $i$ and year $y$,

$\beta$ = manner in which $E(m_{i,y})$ is thought to depend on $F_{i,y}$.

$b$ = parameter required to estimate $\text{VAR}(m_{i,y})$. The larger the $b$, the better a model fits a specific data set.

Because $m_{i,y}$ is the expected number of accidents per mi or per intersection, if Road section $i$ is $L_i$ mi long and has $N_i$ intersections, then the mean and variance for nonintersection and fixed object accidents are $L_iE(m_{i,y})$ and $L_i^2\text{VAR}(m_{i,y})$; the mean and variance for intersection accidents are $N_iE(m_{i,y})$ and $N_i^2\text{VAR}(m_{i,y})$.

For each accident type there are 15 parameters to be estimated: $\beta$, $b$, and 13 values of $\alpha$. These were first estimated using data for all 525 road sections. After some outliers were identified and deleted, the parameters were re-estimated. The likelihood function that these parameters maximize is described in Appendix D of Hauer (*3*). To illustrate, the maximum likelihood parameter estimates for nonintersection accidents are given in Table 1.

It is worth noting that the exponent $\beta$ of AADT is 0.78 for nonintersection accidents (0.71 for intersection accidents and 0.60 for fixed-object accidents). Thus, the relationship between the expected number of accidents and AADT is in each case distinctly nonlinear.

**TABLE 1 Parameter Estimates**

| | |
|---|---|
| $\alpha_1$ | 0.002844 |
| $\alpha_2$ | 0.002885 |
| $\alpha_3$ | 0.002745 |
| $\alpha_4$ | 0.002550 |
| $\alpha_5$ | 0.002662 |
| $\alpha_6$ | 0.002634 |
| $\alpha_7$ | 0.002479 |
| $\alpha_8$ | 0.002699 |
| $\alpha_9$ | 0.002601 |
| $\alpha_{10}$ | 0.002709 |
| $\alpha_{11}$ | 0.002373 |
| $\alpha_{12}$ | 0.002541 |
| $\alpha_{13}$ | 0.002414 |
| $\beta$ | 0.77606 |
| b | 5.571 |

## HOW EFFECT ON SAFETY WAS ESTIMATED

In this section the method used to estimate the effect resurfacing on safety is described. It is somewhat more complex than the more familiar "before-after-with-comparison-group" method. The aim was to (a) use a long accident history to enhance estimation accuracy, (b) account explicitly for changes in traffic flow and for changes in the uncontrolled factors in the "before" and "after" periods, and (c) eliminate the regression-to-mean threat to the validity of the estimates.

These aims can be attained within the Empirical Bayes approach to estimation. In general, the process can be thought to entail four steps.

### Step 1

Estimate for each road section what the expected number of accidents per year was during the before-treatment years. Two clues are used for this purpose: (a) the history of accident counts on the road section and (b) the expected count of accidents for road sections with the same traits (AADT, length, number of intersections) in the reference population. This procedure eliminates bias due to possible regression to the mean. The information needed for (b) is the parameters of the multivariate models that link the number of accidents on road sections of a reference population to their AADT, length, and number of intersections. Here Step 1 was based on the following development explained fully in Hauer (*3*):

Let Road section $i$ have accident counts $x_{i,1}, x_{i,2}, \ldots, x_{i,n}$ in Years $y = 1,2, \ldots, n$. Collectively, these form the Vector $\boldsymbol{x}$. The information contained in $\boldsymbol{x}$ can be combined with the information contained in $E(m_{i,y})$ and $\text{VAR}(m_{i,y})$ obtained earlier into $E(m_{i,1}|\boldsymbol{x})$ using

$$E(m_{i,1}|\boldsymbol{x}) = \frac{b + \sum_{y=1}^{n} x_{i,y}}{a + L_i \sum_{y=1}^{n} C_{i,y}} \quad (2)$$

In this $E(m_{i,1}|\boldsymbol{x})$ is used to estimate the $m$ of Road section $i$ in Year 1, $n$ is the number of time periods for which accident data are used, and $a$ and $C_{i,y}$ are given by

$$a = b/E(m_{i,1}) \quad (3)$$

and

$$C_{i,y} = (\alpha_y F_{i,y}^{\beta})/(\alpha_1 F_{i,1}^{\beta}) \quad (4)$$

### Step 2

Using the results of Step 1, predict what the expected number of accidents on that road section would have been in the period after resurfacing if it had not been resurfaced. In this step, one has to account for changes in traffic from the "before" years to the "after" year, as well as for changes in the various uncontrolled factors.

Here, based on the earlier development, $E(m_{i,y}|\boldsymbol{x}) = C_{i,y}E(m_{i,1}|\boldsymbol{x})$, it follows that for a road section that is $L_i$ mi long,

$$E(L_i m_{i,y}|\boldsymbol{x}) = L_i C_{i,y} E(m_{i,1}|\boldsymbol{x}) \quad (5)$$

### Step 3

Estimate for that road section what was the expected number of accidents during the after period with resurfacing in place. Compare this to the result of Step 2. Estimate the safety effect.

### Step 4

Repeat Steps 1, 2, and 3 for all treated road sections. Combine the results for individual road sections to obtain estimate of mean effect.

To illustrate, estimate $E(m_{1,1})$ and $\mathrm{VAR}(m_{1,1})$ for nonintersections accidents of a site that in 1975 (ie., for Year 1) is estimated to have had AADT = 1199 and is 1.6 mi long. From Table 1 $\alpha_1$ = 0.002844, $\beta$ = 0.77607, and $b$ = 5.571. The estimate of $E(m_{1,1})$ is $0.002844 \times 1199^{0.77606} = 0.697$ nonintersection accidents/mi per year; $\mathrm{VAR}(m_{1,1}) = 0.697^2/5.571 = 0.0872$, which makes a standard deviation of $\sqrt{0.0872} = 0.295$ accidents/mi per year. The estimate of $b$ is 5.571 as given in Table 1. Therefore the estimate of $a$ is 5.571/0.697 = 7.99.

For this site there are "before resurfacing" accident counts for 7 full years (1975 to 1981) and 3 months in 1982. Thus, $n$ = 8. The accident count vector $\boldsymbol{x}$ is 1, 4, 5, 1, 4, 1, 3, 0. Their sum is 19. Because $b$ was found to be 5.571, the numerator in Equation 2 is 5.571 + 19 = 24.571. For the denominator of Equation 2 one needs values of $C_{i,y}$. These are calculated by Equation 4 and shown in Table 2.

One now can calculate the denominator of Equation 2. The value of $a$ calculated earlier was 7.993. The length of this road section was said to be 1.6 mi. The sum of the $C$'s for 7 full years is 6.325. Only 3 months of accident data for the 8th year are used. Therefore, $C_{1,8} = 0.848 \times 3/12 = 0.212$. This makes the sum of $C$'s to be 6.325 + 0.212 = 6.537. Thus, the denominator in Equation 2 is 7.993 + 1.6 $\times$ 6.537 = 18.452. Doing the calculations of Equation 2, one finds that $E(m_{1,1}|1, 4, 5, 1, 4, 1, 3, 0) = 24.571/18.452 = 1.33$ accidents/mi/year in 1975.

Note that if one were to take the raw accident count for the 7 full years, one would obtain 19/(7 $\times$ 1.6) = 1.70 accidents/mi per year. This amounts to setting $a = 0$ and $b = 0$ and making all $C$'s 1. Doing so means that one does not recognize the variations in traffic from year to year or the variations that go with the passage of time. (This is why the usual advice is not to extend the "before" period beyond three years. The fear is that, if corrections for changes in traffic and other factors are not applied, accident counts from the distant past are of doubtful use when projections are to be made into the "after" period.) The advantage of accounting for changes in traffic and other factors as is done in Equation 2 is to allow the use of a longer "before" history of accidents counts. This enhances the accuracy of estimation. The incorporation of Parameters $b$ and $a$ in Equation 2 reflects the influence of the reference population and ensures that the result is not biased by regression to the mean.

What the expected number of accidents on this site would have been can now be predicted if no resurfacing had taken place. Using Equation 5 one predicts, for example, for 1983 (y = 9, the first full year after resurfacing), that $E(L_1 m_{1,9}|\boldsymbol{x}) = 1.6 \times 0.824 \times 1.33 = 1.76$ accident per year. This prediction has been built up gradually from several pieces of information.

- Accident history of the site during the "before" period taking into consideration the changing AADT in the "before" years and also accounting for the year-to-year change in various uncontrolled factors.
- Distribution of $m$'s at similar sites, based on the multivariate model.
- AADT in 1983 and the effect of the uncontrolled factors for that year.

The next step is obvious. In 1983, after the site had been resurfaced, it recorded three nonintersection accidents. Without resurfacing 1.76 such accidents would have been expected. Thus, for this site and year, there were 1.24 more nonintersection accidents than expected. Since changes in traffic and other factors were accounted for, the noted difference is attributable to resurfacing.

Of course, one can not form an opinion about the safety effect of resurfacing on the basis of one site and one year. The effect will be added up for all sites and examined for all years. The hope is that, by doing so, sufficiently accurate results can be obtained. This is the subject of Step 4. Since the suspicion is that the effect of resurfacing changes with time, an attempt will be made to examine the effect on a monthly not a yearly basis. Indexes of monthly variation are used for this purpose.

**TABLE 2 Calculation of $C_{1,y}$**

| y | a | $F_{1,y}$ | $E\{m_{1,y}\}$ | $C_{1,y}$ | Cum $C_{1,y}$ |
|---|---|---|---|---|---|
| 1 | 0.002844 | 1199 | 0.697 | 1.000 | 1.000 |
| 2 | 0.002885 | 1201 | 0.708 | 1.016 | 2.016 |
| 3 | 0.002745 | 1175 | 0.662 | 0.950 | 2.966 |
| 4 | 0.00255 | 1163 | 0.610 | 0.875 | 3.841 |
| 5 | 0.002662 | 1098 | 0.609 | 0.874 | 4.715 |
| 6 | 0.002634 | 1042 | 0.579 | 0.830 | 5.546 |
| 7 | 0.002479 | 1038 | 0.543 | 0.779 | 6.325 |
| 8 | 0.002699 | 1038 | 0.591 | 0.848 | 7.173 |
| 9 | 0.002601 | 1049 | 0.575 | 0.824 | 7.997 |
| 10 | 0.002709 | 1083 | 0.614 | 0.880 | 8.878 |
| 11 | 0.002373 | 1104 | 0.546 | 0.782 | 9.660 |
| 12 | 0.002541 | 1140 | 0.599 | 0.859 | 10.519 |
| 13 | 0.002414 | 1228 | 0.603 | 0.865 | 11.384 |

## EFFECT OF RESURFACING IN FAST TRACK PROJECTS

There is information about 82 fast-track sites, that is, projects involving primarily resurfacing. The effect of resurfacing on safety for three accident types—nonintersection, intersection, and fixed object—will be estimated.

### Effect of Resurfacing on Nonintersection Accidents

By using the method in the previous section, the results in Table 3 were obtained. Thus, during the first month after resurfacing, 20.91 nonintersection accidents would be expected if no resurfacing had taken place, and the average pre-resurfacing pavement conditions were to prevail (Column 2). The accumulative sum of the expected numbers is given in Column 3. Actually, 24 such accidents were recorded in the first month after resurfacing (Column 4). Both numbers, 20.91 and 24, are the sum for the 82 fast-track project sites (Column 5). The difference between 24 and 20.91 is the excess number of accidents, Column 6. The last column lists the cumulative excess. Thus, at the end of the third month after resurfacing, the cumulative excess is estimated to be 10.06 nonintersection accidents. The table is interrupted in several places. Because not all 82 sites were resurfaced at the same time, not all had the same length of "after" history. For example, only 40 sites had a history longer than 74 months after resurfacing.

**TABLE 3 Summary Calculations**

| After Months (1) | Expected Accid. (2) | Cumul. Expected (3) | Accident Count (4) | Number of sites (5) | Excess Accid. (6) | Cumul. Excess (7) |
|---|---|---|---|---|---|---|
| 1 | 20.91 | 20.91 | 24 | 82 | 3.09 | 3.09 |
| 2 | 23.35 | 44.26 | 27 | 82 | 3.65 | 6.74 |
| 3 | 23.68 | 67.94 | 27 | 82 | 3.32 | 10.06 |
| 4 | 20.35 | 88.29 | 17 | 82 | -3.35 | 6.71 |
| ... | | | | | | |
| 30 | 18.07 | 605.37 | 17 | 82 | -1.07 | 124.63 |
| 31 | 17.91 | 623.27 | 12 | 82 | -5.91 | 118.73 |
| ... | | | | | | |
| 41 | 18.82 | 829.78 | 22 | 82 | 3.18 | 138.22 |
| 42 | 17.02 | 846.80 | 18 | 82 | 0.98 | 139.20 |
| ... | | | | | | |
| 60 | 21.08 | 1203.41 | 21 | 82 | -0.08 | 133.59 |
| 61 | 23.57 | 1226.98 | 31 | 82 | 7.43 | 141.02 |
| ... | | | | | | |
| 73 | 16.24 | 1438.00 | 12 | 50 | -4.24 | 106.00 |
| 74 | 16.97 | 1454.97 | 20 | 40 | 3.03 | 109.03 |

The data of Table 3 are shown in Figure 1. The asterisks in Figure 1 belong to the left scale and show the accumulation of the excess of nonintersection accidents with time after resurfacing (the last column in Table 3). The solid line in Figure 1 belongs to the right scale and shows the accumulation of the number of accidents expected without resurfacing. Note that the two scales differ by a factor of 10. To make interpretation easier, the same ratio of left and right scales also will be used in the subsequent figures.

The orderliness of the results is remarkable. For the first 30 months or so, there is an excess averaging 4.15 nonintersection accidents/month. The standard deviation of this average is 0.93. (So, even from the statistical point of view, the excess must be thought real. A null hypothesis that there was no increase in nonintersection accidents is clearly rejected). Over 30 months the excess accumulates to about 125 nonintersection accidents (with a standard deviation of 28). Thus, it is estimated that, if no resurfacing had taken place and if the pre-resurfacing pavement conditions continued to prevail, 125 fewer nonintersection accidents would have been recorded within 30 months. Over the same period of time about 605 nonintersection accidents would be expected without resurfacing. Thus, the increase is of about 21 percent (124/605 = 0.21). After the first 30 months, there is a 10-month transition during which the monthly accident excess gradually diminishes. The detrimental effect of resurfacing appears to vanish after about 40 months. Over these 40 months, more than 135 nonintersection accidents has accumulated, with a standard deviation of 33. Without resurfacing one would have expected to accumulate by that time 810 nonintersection accidents.

After 40 months there is a plateau that lasts until about 63 months after resurfacing. During this period the average monthly excess is 0.28 nonintersection accident. The standard deviation of this average is 0.79 accident. Thus, it appears that on the plateau the number of accidents is approximately what would have been expected without resurfacing but with pavement conditions that prevailed before resurfacing. Following the plateau, there is a gradual decline. That is, beginning with month 64 after resurfacing, there are fewer nonintersection accidents every month than one should expect if the pre-resurfacing pavement conditions continued to prevail. The number of sites having such a long post-resurfacing history is small. Therefore, one can not say whether the noted decline is real. However, inasmuch as similar declines will later be noted for other accident types, the trends appear to have substance. One may speculate that after more than 5 years of service, the pavement condition is on average worse than what it was in the before-resurfacing period. Just as a new pavement was seen to generate an excess of nonintersection accidents, it should not be surprising that old pavements seem to have the opposite effect.

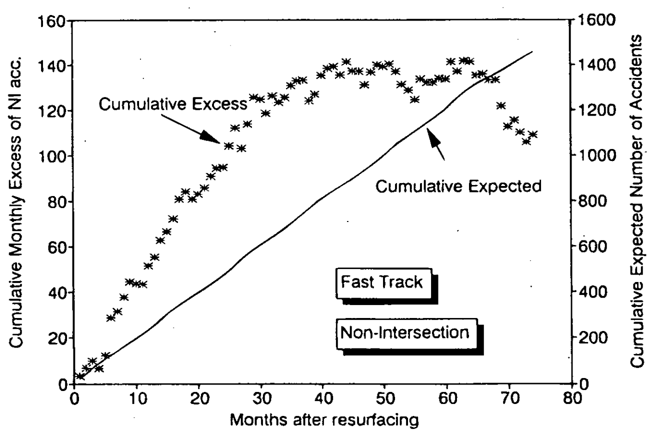


**FIGURE 1 Safety effect of resurfacing on nonintersection accidents in 82 fast track projects.**

### Effect of Resurfacing on Fixed-Object Accidents

In general, the detrimental effect of resurfacing on fixed-object accidents was found to be similar to that observed earlier for nonintersection accidents. For the first 30 months, there is an average excess of 3.31 fixed-object accidents per month. The standard deviation of this average is 0.69 accident. This amounts to an excess of nearly 100 fixed-object accidents in 30 months after resurfacing. The standard deviation here is 21 accidents. Over the same period of time about 290 fixed-object accidents would be expected without resurfacing. Thus, the increase is 34 percent. There is a hint of a plateau at about 40 months. The cumulative excess after 63 months is 130 with a standard deviation of 29 fixed-object accidents. As for nonintersection accidents, there is a clear intimation of a decline after 63 months.

### Effect of Resurfacing on Intersection Accidents

Two of the 82 road fast-track road sections have no intersections. Therefore, the results here are based on 80 road sections. The accumulation of excess intersection accidents and the number expected without resurfacing is shown in Figure 2.

There are two main differences between the effect of resurfacing on intersection accidents (Figure 2) and its effect on nonintersection accidents (Figure 1). First, the hump that separates the period when more than the expected number of accident occurs from the period when fewer then expected accidents materialize occurs much earlier. Second, the absolute excess is smaller, and therefore the results are not as reliable.

For the first year after resurfacing, there are more intersection accidents than would be expected if the road sections had not been resurfaced. The excess is 2.92 intersection accidents/month with a standard deviation of 1.21 for a total of 35 intersection accidents with a standard deviation of 15. By the end of the first year, 101 intersection accidents would be expected without resurfacing. Thus, there was an increase of 35 percent.

Disregarding the undulations, from the end of the first year until Month 32 there is a plateau. The excess here is 0.01 with a standard deviation of 0.50 intersection accidents per month. From Month 33 to Month 63 (where there are still data for all 80 road sections), each month there are fewer accidents than would be expected if there had been no resurfacing and the pre-resurfacing pavement conditions continued to prevail. The average monthly excess is −2.04 intersection accidents per month with a standard deviation of 0.50.

In Figure 1, a decline was already noted, that is, a negative excess. Here for the first time its magnitude can be estimated. The hypothesis has been advanced earlier that, just as new and smooth pavement is associated with a positive excess, as the pavement ages after a turning point the excess becomes negative. Although the hypothesis is plausible, it is merely a hypothesis. Here one must ask why the turning point for intersection accidents occurs earlier than for nonintersection accidents and by what mechanism can resurfacing and pavement aging affect the frequency of intersection accidents?

One also needs to ask whether there is some factor neglected in the analysis that could have brought about these results. Could perhaps the change in the definition of intersection accidents be responsible for the decline? We think not. Firstly, the decline starts about 32 months after resurfacing while the change in definition occurred (May 1983) perhaps 10 to 20 months after the projects were finished (either in fall 1981 or 1982). Second, no change was detected in the count of intersections accidents coinciding with the change in definition. Third, whatever the effect of the change in definition, it is reflected in the corresponding $\alpha$s.

## EFFECT OF RESURFACING AND OTHER MODIFICATIONS IN R&P PROJECTS

The R&P projects include various additional improvements with resurfacing. Thus, the effect to be estimated is not only of resurfacing but the joint effect of all modifications implemented. There is information about 55 R&P sites. As in the previous section, the joint effect of resurfacing and other improvements on safety will be estimated for three accident types—nonintersection, intersection, and fixed-object.

### Effect on Nonintersection accidents

The accumulation of excess nonintersection accidents and of the number of nonintersection accidents expected without resurfacing versus months after resurfacing is shown in Figure 3.

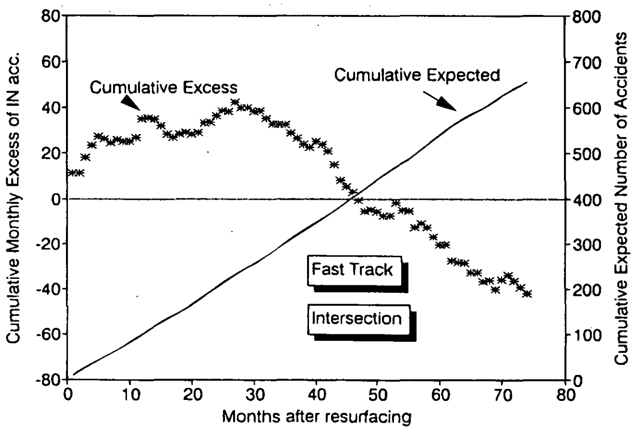


**FIGURE 2 Safety effect of resurfacing on intersection accidents in 82 fast track projects.**

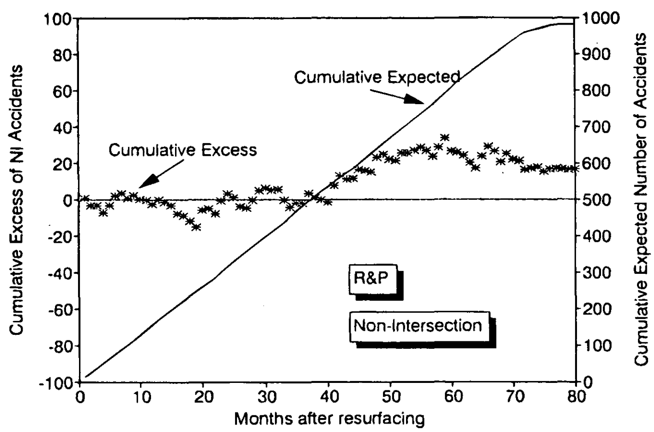


**FIGURE 3 Safety effect of improvements on nonintersection accidents in 55 R&P projects.**

The comparison is with Figure 1, and the contrast is stark. Without much analysis, one can state that in Figure 3 there is no discernible change in the number of nonintersection accidents from what would be expected if these projects had not been implemented and the pavement condition remained as in the pre-improvement period.

### Effect on Fixed-Object Accidents

Although the corresponding figure is not shown here, its examination would show that the joint effect of the resurfacing and other improvements was to make the number of fixed-object accidents just what it would have been if no improvements had been undertaken and the pavement conditions from before the improvement continued to prevail, just as is true for the nonintersection accidents in Figure 3.

### Effect on Intersection Accidents

Four of the 55 R&P road sections have no intersections. Therefore, the results here are based on 51 road sections. The accumulation of excess intersection accidents and the number expected without resurfacing are shown in Figure 4.

As is clear, the R&P project improvements are associated with a reduction in the number of intersection accidents for a long period of time. The horizontal tail after Month 70 merely signifies that very few sections have such a long "after" history. The full 51 road sections can be followed only for 60 months.

During that 60-month period, the average number of intersection accidents was reduced by 2.78 per months, with a standard deviation of 0.31 accidents. This accumulates over the 60-month period to a reduction of 167 intersection accidents, with a standard deviation of 19. By that time, 572 intersection accidents would have been expected if the R&P project had not been undertaken and pavement conditions remained constant. This amounts to a 29 percent reduction in intersection accidents.

Again there is the question Is this real? What aspect of the R&P projects can be thought to act on intersection accidents? On one hand, the results here are internally consistent with what has been found for fast-track projects. In fast-track projects, resurfacing was associated with an increase in nonintersection accidents and a slight increase followed by decline of intersection accidents. In R&P projects nonintersection accidents were found to remain stable while intersection accidents declined steadily from the end of resurfacing. Thus, there is a link between how nonintersection and intersection accidents appear to respond. On the other hand, a mechanism by which the kinds of actions undertaken in R&P projects can diminish the number of intersection accidents is unknown.

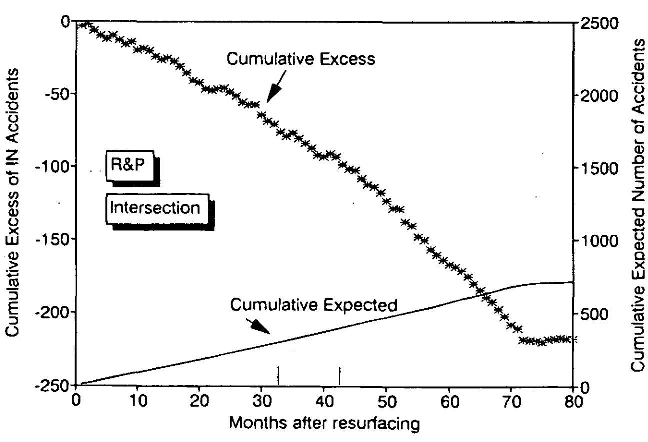


**FIGURE 4 Safety effect of improvements on intersection accidents in 51 R&P projects.**

## SUMMARY AND CONCLUSIONS

In the early 1980s, two kinds of resurfacing projects were undertaken. The task was to ascertain whether projects involving only simple resurfacing (82 fast-track projects, 226.7 mi) perform less well from a safety viewpoint than similar resurfacing projects where roadside and roadway safety improvements have been incorporated (55 R&P projects, 137.2 mi).

The overall answer is yes. In fast-track projects, safety initially declined; in R&P projects safety improved. Since the safety effect of resurfacing changes with the passage of time and differs from one type of accident to another, one can not describe the difference between fast-track and R&P projects by a single number. Table 4 is an attempt at a succinct summary. Another conclusion that emerges from this work is that with the first 6 to 7 years of pavement life, safety improves as the pavement ages.

Retrospective studies of this kind can provide estimates of what the effect on safety of some intervention was. However, to say in such a study how the estimated effect came to be is difficult. There are no data on how speed has changed, how pavement friction was affected, what were the changes in traffic volumes on the crossing legs of intersections, no knowledge of when shoulders were backed up in fast-track projects, or details about what specific improvements were made in which R&P projects. Because the effect of these interventions on safety appears to be large, this lack of explanation is troubling. One would have more confidence in the results if these could be attributed to causes.

Still, the results display a pleasing internal consistency. One can not imagine any element of method or of data analysis that could be incorrect and still leave this internal harmony intact. It is also reassuring that the results presented here are in many ways similar to the results obtained earlier by the NYDOT staff when using part of the data in simple before-and-after comparisons and in comparisons involving the use of control sections.

It appears clear that the kind of resurfacing that went with fast-track projects affected safety differently from the kind of resurfacing associated with R&P projects. This leads to the conclusion that resurfacing as referred to in the professional literature may cover a heterogeneous set of activities. When discussing the effect of resurfacing on safety, one should be specific about the kind of activities performed. Lumping together the safety effect of diverse kinds of resurfacing may give a fuzzy picture.

There are two main novel aspects to the method used in this study. First, it is sensible to expect the effect of resurfacing on safety to change with time as the pavement ages. The method used facilitates the examination of this aspect. Second, the accuracy of studies of this kind is often limited by the sparsity of accident data. The method used here allows the use of a long "before" accident history and enhances accuracy by using information from the reference population.

**TABLE 4 Summary of Results**

| FAST TRACK | | | | R&P | | |
|---|---|---|---|---|---|---|
| Non- Intersection | | Intersection | | Non-Intersection | Intersection | |
| Mo. 0-30 | +21% | Mo. 0-12 | +35% | No Change | Mo. 0-70 | -29% |
| Mo. 40-63 | 0% | Mo. 13-32 | 0% | | | |
| Later | decline(?) | Later | -23% | | | |

The central theme of this study was to assess the effect of the two kinds of treatment on safety. En route, two by-products have been generated. One is a procedure for estimating AADTs for every road section and every year on the basis of traffic counts conducted once in 3 to 4 years. The other by-product consists of the multivariate models, which, with a slight extension, can be the basis of a rational procedure for the identification of hazardous locations.

The work reported here had to be done within time and on budget and is not as complete as it could have been. The procedure for estimating AADT is somewhat ad hoc; the investigation of the correspondence between the reference and comparison groups is limited; with added effort it would have been possible to investigate separately the effect of resurfacing on property damage and on injury accidents; it would also have been possible to examine the effect of the construction period itself.

There is one deficiency that became apparent only after the analysis was completed. The results indicate that as the pavement ages accidents diminish. Because all treated road sections were resurfaced within 1 year of each other, their pavements must have been deteriorating approximately in tandem; they were all in need of repair just before resurfacing and in good shape 5 to 7 years earlier. If so, there is a systematic factor that the analysis in Step 1 neglected. The net effect of this deficiency is that prediction of what would be expected without resurfacing has been produced as if a constant pavement condition prevailed during the entire before-resurfacing period. This logical deficiency applies equally to the fast-track and the R&P projects and is unlikely to affect any of the conclusions materially.

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