Before and After study to identify the Accident Reduction Factors After Pavement Resurfacing

Maria Grazia Augeri - Salvatore Cafiso

Department of Civil and Environmental Engineering
School of Engineering, University of Catania

SYNOPSIS

An important task in the rehabilitation of existing roads is the identification of the most suitable treatments in order to improve safety. The estimation of safety effectiveness of the maintenance operations, is a complex problem depending on the particular nature of the accident phenomenon.

Therefore, a correct definition of the analysis methodologies is necessary with the aim of avoiding errors of estimation. These mistakes can be determined by random fluctuations of the accidents (regression to the mean), by the variability of the environmental and traffic conditions and by the small sample size.

In the present paper some procedures of before-and-after analysis are presented. Based on a literature review and on previous studies, the Bayesian method was used to correct the regression to the mean phenomenon. The comparison between the Simple and the Bayesian methods confirmed how the former tends to overestimate the efficiency of treatments compared to the latter. The data on accident and traffic flow collected on a sample of 21 sites where resurfacing treatment was carried out, allowed the values of Accident Reduction Factors related to different site typology (tangent, curvilinear, tangent with junction, curvilinear with junction) and/or accident type (all accident, out of control, hit permanent obstacle, hit temporary obstacle accidents and wet pavement accidents) to be determined. The results showed large differences in the safety effectiveness of the resurface treatment with respect to the different site typologies and accident types.

Experimental Development of Accident Reduction Factors After Pavement Resurfacing

INTRODUCTION

In a rational process of road management, especially as regards safety, monitoring of the post-maintenance situation is fundamental for a global evaluation of the positive or negative effects of the interventions.

The results of such evaluations are very useful for the road Agencies who carried out the works in as far as they allow the effectiveness of the investment to be verified, in terms of a reduction in accidents with respect to all the costs connected to them (deaths, injuries, damage to the infrastructure, etc.).

Besides, it can be important to determine the effects that a particular type of intervention has had on the number of accidents at one site, in order to draw suggestions for future applications at sites with similar problems.

Before-and-After studies aim at evaluating the effectiveness of an intervention comparing the conditions observed before and after the carrying out of the works. In effect, it is more correct to say that the situation observed in the *after* period must be compared with the number of expected accidents for that site, if works had not been carried out.

As regards the post-maintenance situation, the most useful parameter is represented by the number of accidents taking place in a significant observation period following on from the completion of the works.

Instead, the evaluation of the situation hypothesising an absence of works is more complicated. The simplest method would be to assume that the number of accidents observed in a significant period of time before works would have remained unchanged in the period immediately following if the works had not been carried out.

However, this value does not represent a good estimate of the long term situation at that site. Usually, the sites where it has been decided that works will be carried out are those having a higher number of accidents compared to the average number for road networks with similar characteristics.

On these sites, therefore, in the after period the number of accidents tends to go down, also in the absence of any intervention, due to the effect of regression to the mean, and so, the evaluations performed with reference to this parameter could lead to an overestimation of the effectiveness of the treatments (Hauer,1997; Elvik, 2000; Shen 2003).

For this reason, the problem of estimating the expected number of accidents at a site in the absence of works must be undertaken with great attention, choosing the most suitable methods in order to reduce possible evaluation errors deriving from random fluctuations linked to the particular nature of the phenomenon.

EVALUATION OF THE EFFECTIVENESS OF TREATMENTS

Before looking in detail at the analysis methods for the estimation of the variables, it is necessary to define the most suitable indicators for the evaluation of the efficacy of treatments in terms of a reduction in the number of accidents:

$\theta = \lambda/\pi$	Accident reduction ratio
$ARF = 100*(1 - \theta)$	Accident reduction factor

where:

π represents the value of the number of expected accidents in the *after* period if the treatment had not been made (estimated value), and it is a random variable with Poisson probability density function;

λ represents the value of the number of accidents in the period following on from the carrying out of treatment (observed value), and it is also a Poisson random variable.

Due to the fact that π and λ represent random variables of unknown populations, it is necessary to proceed with estimations of the distribution parameters and the same is true for all the variables deriving from them (θ and ARF) (Hauer,1997):

$$\bar{\theta} = \left(\bar{\lambda}/\bar{\pi}\right)/\left[1 + \mathrm{VAR}(\pi)/\bar{\pi}^2\right]$$

mean value

$$\mathrm{VAR}(\theta) = \bar{\theta}^2 \cdot \left[\left(\mathrm{VAR}(\lambda)/\bar{\lambda}^2\right) + \left(\mathrm{VAR}(\pi)/\bar{\pi}^2\right)\right]/\left[1 + \mathrm{VAR}(\pi)/\bar{\pi}^2\right]^2$$

variance

Where mean $(\bar{\pi}, \bar{\lambda})$ and variance ($\mathrm{VAR}(\pi)$, $\mathrm{VAR}(\lambda)$) are estimated values and $[1+\mathrm{VAR}(\pi)/\pi^2]$ is a correction factor to make the estimator unbiased.
As the exact calculation of the θ parameter strictly depends on the correct estimation of π and its variance, literature proposes various solutions offering different degrees of reliability and complexity of calculation.
Four types of before-and-after methods are commonly used in literature (Hauer,1997; Shen, 2003).

1. The simple before-and after study method;
2. The before-and-after study with control sites method;
3. The before-and-after study with Empirical Bayes method;
4. The before-and-after study with Empirical Bayes and control sites method.

The first is easy to use but it does not consider the variability linked to the accident phenomenon and the effects of the regression to the mean.
The other methods for a correct estimation of π tend to correct the previous mistakes using control sites (control sites method) or considering the accident rate as a random variable (Bayesian method). Finally, there is also the possibility of combining the control sites method with the Bayesian method (Bayesian method with control sites).
In the before-and-after study with control sites method, accident data at the comparison group are used to estimate accidents at the treated sites if the treatment had not been made. The control sites can be defined as a group of sites similar to the treated sites in traffic and geometric characteristics. This method can provide an accurate estimate of π, but its use is very complicate since it is difficult to have a suitable sample of control sites (Cafiso, 2001; Yuan, 1999).
For this reason in this research it was decided to adopt the methods 1 and 3 that will be described in detail in the following paragraphs.

SIMPLE BEFORE-AND-AFTER STUDY METHOD

This is one of the simplest methods for checking the safety benefits of an intervention through a direct comparison of the number of accidents taking place in the before and after periods.
It is assumed, therefore that:

$$\bar{\lambda}_i = L_i \qquad \mathrm{VAR}(\lambda_i) = L_i$$
$$\bar{\pi}_i = R_{Ei} \cdot K_i \qquad \mathrm{VAR}(\pi_i) = R_{Ei}^2 \cdot K_i$$

where:
L_i : number of accidents observed in the *after* period at site i;
K_i : number of accidents observed in the *before* period at site i;
$R_{Ei} = E_A / E_B$: exposure ratio;
$E_{Ai} = n_{Ai} \times (365\ AADT_{Bi}) \times Length_i$: exposure during *after* period at site i (10^6 vehicle per kilometre);
$E_{Bi} = n_{Bi} \times (365\ AADT_{Ai}) \times Length_i$: exposure during *before* period at site i (10^6 vehicle per kilometre);

n_{Bi} : number of years of before period,
n_{Ai} : number of years of after period,
AADT : Annual Average Daily Traffic.
This method has the advantage of being simple to use, but it does not take into account some important elements such as the regression to the mean and the possibility of changes in the accident phenomenon due to external factors such as traffic characteristics and composition, rules of the road (Hauer,1997; Elvik, 2000).

EMPIRICAL BAYES BEFORE-AND-AFTER STUDY METHOD

In general the Bayesian method is the most greatly used for estimating accident rate.

With the Bayesian method the accident rate is considered as a random variable having its own probability distribution

Such an approach uses all the information available relating to the phenomenon in order to build up a prior distribution of the accident rate (ar) which is later modified according to the data recorded for each single site, so as to arrive at a posterior distribution of ar_i for the site (i) from which to obtain the estimation (π_i). The accident rate was assumed equal to the ratio between the number of accident (N_i) and exposure (E_i):

$$ar_i = \frac{N_i}{E_i}$$

The prior distribution can be obtained by having a sufficient quantity of data available relating to a representative sample of the population to which the site belongs.

The Bayesian type approach presupposes two fundamental hypotheses:

without treatments, in each site accidents occur according to a Poisson probability density function $P(K/\kappa)$ with mean κ :

$$P(K/\kappa) = \frac{\kappa^K e^{-\kappa}}{K!} \qquad (K= 0,1,2,3,.....)$$

The accident rate (ar) varies between the different sites and its value for each site is not known, but it is considered as a random variable. It is supposed that the prior distribution of “ar” is described by a gamma function g (ar):

$$g(ar) = \frac{\beta_0{}^{\alpha_0} ar^{\alpha_0 - 1} e^{-\beta_0 ar}}{\Gamma(\alpha_0)}$$

with ‘α_0’ and ‘β_0’ parameters of the distribution.

This distribution has a mean value equal to α_0/β_0 and a variance equal to α_0/β_0^2.

If in the before period the total number of accidents observed at site i is equal to K_i, under hypotheses 1 and 2, and applying Bayes theorem, the posterior distribution of ar_i will also be gamma function with α_ι and $\beta\imath$ parameters:

$$\alpha_i = \alpha_o + K_i$$
$$\beta_i = \beta_o + E_{Bi}$$

Therefore, the mean value $\overline{ar}_i$ and the variance $VAR(ar_i)$ of the accident rate at site ‘i’ without treatment, are the mean and the variance of the posterior distribution:

$$\overline{ar}_i = \frac{\alpha_0 + K_i}{\beta_0 + E_{Bi}}$$

$$VAR(ar_i) = \frac{\alpha_0 + K_i}{(\beta_0 + E_{Bi})^2}$$

From a reference population available or from a group of sites having similar characteristics to the analysed site, it is possible to estimate the mean $\overline{ar}_0$ and the variance $VAR(ar_o)$ with the method of sample moments and, therefore, β_0 and α_0 :

$$\beta_0 = \frac{\overline{ar}_0}{VAR(ar_0)}$$

$$\alpha_0 = \frac{\overline{ar}_0^{\,2}}{VAR(ar_0)}$$

The values of $\overline{\pi}_i$ and VAR (π_ι) relating to site i can be determined using the following relation:

$$\overline{\pi}_i = R_{Ei} \cdot \left(\overline{ar}_i \cdot E_{Bi}\right) = \overline{ar}_i \cdot E_{Ai}$$

$$VAR(\pi_\iota) = R_{Ei}^2 \cdot VAR(ar_i) \cdot E_{Bi}^2 = VAR(ar_i) \cdot E_{Ai}^2$$

SAMPLE APPLICATION

The procedures already defined were applied to a sample composed of 21 sites on two-lane rural roads, on which resurfacing works had been carried out. The sections have a length of between 0.15 m and 2.60 Km. Table 1 shows the data relating to the sites analysed.

TABLE 1 Experimental Sample Data

Site	Length (km)	Exposure (10^6 vehicles km)		Number of accidents		Construction period		Site typology
		before	**after**	**before**	**after**	**from**	**to**	
1	0,50	11,6	11,6	3	6	14/05/98	12/08/98	Tangent with junction
2	1,42	51,83	51,83	5	6	14/05/98	12/08/98	Curvilinear
3	0,90	21,49	21,41	1	5	10/07/98	04/08/98	Tangent
4	0,40	9,75	9,52	20	24	10/07/98	04/08/98	Tangent with junction
5	1,80	68,99	67,34	4	4	10/07/98	04/08/98	Curvilinear with junction
6	1,56	49,82	65,48	16	28	25/11/97	13/02/97	Tangent with junction
7	1,28	20,91	27,48	11	8	02/12/97	18/02/98	Tangent with junction
8	0,96	15,68	20,61	7	10	02/12/97	18/02/98	Tangent
9	0,26	4,18	5,50	3	4	02/12/97	18/02/98	Tangent
10	2,62	42,73	56,16	11	8	02/12/97	18/02/98	Tangent with junction
11	2,19	36,79	41,39	2	2	14/05/98	09/10/98	Tangent with junction
12	0,42	7,06	7,94	1	2	14/05/98	09/10/98	Curvilinear with junction
13	0,97	7,37	8,29	2	3	14/05/98	09/10/98	Curvilinear
14	0,78	12,74	16,74	6	12	25/11/97	13/02/97	Curvilinear with junction
15	0,58	9,47	12,45	5	3	25/11/97	13/02/97	Tangent with junction
16	0,39	6,88	6,72	0	8	10/07/98	04/08/98	Tangent
17	1,00	17,64	17,22	10	15	10/07/98	04/08/98	Curvilinear with junction
18	0,87	14,80	14,80	6	3	14/05/98	12/08/98	Tangent with junction
19	0,30	5,10	5,10	2	5	14/05/98	12/08/98	Tangent
20	0,16	2,72	2,72	0	3	14/05/98	12/08/98	Tangent
21	1,04	17,69	17,69	6	1	14/05/98	12/08/98	Curvilinear

Table 1 shows for each site: length of the treated stretch, exposure and number of accidents in before and after period, construction period and site typology. The site typology is related to the predominant alignment characteristic (tangent or curvilinear) and the presence of junctions within the treatment site.

To carry out α_0 and β_0 a sample of 110 sites was used with the same characteristics of the studied sites, representative of the population to which they belong.

The database of accidents includes crashes from January 1995 to December 2001. They were collected from the Italian Police and Carabinieri reports. Accident variables included date, location, time, collision type, weather conditions, number of fatalities and injuries and pavement condition.

In this way a sufficient number of years of accident data for before and after periods were available. Accidents occurring during the construction period were excluded from the analysis. In the first approach the comparison included all accidents which occurred in the before and after periods. To refine the research in a successive analysis only the target accidents more directly related to the resurfacing were considered.

The target accidents assumed were:

out of control with no collision, hit permanent obstacle, hit temporary obstacle

accidents on wet pavement.

Obviously, for such types of accident it was necessary to redefine both the prior distribution and the posterior distribution for the different sites (Table 2)

TABLE 2: Parameters of Prior Distribution

Accident category	Number of Accident	α_o	β_o
Out of control with non collision, Hit permanent obstacle, Hit temporary obstacle	162	0.36	7.52
wet pavement	94	0.20	6.71
total	622	1.41	7.11

Evaluation of the Site Accident Reduction Factor

Applying the empirical Bayesian method, accident reduction factors were obtained for each site and for different accident categories (Table 3).

TABLE 3: Accident Reduction Factors for the Investigated Sites

Site Typology	Site Number	Empirical Bayesian method analysis			Simple analysis
		Out of control with no collision, Hit permanent obstacle, Hit temporary obstacle	Wet pavement	All accident types	All accident types
Tangent with junction	Site 1	-21%	100%	-79%	-50%
	Site 4	100%	59%	-90%	-17%
	Site 6	-221%	79%	-32%	-25%
	Site 7	69%	68%	39%	49%
	Site 10	-6%	27%	47%	49%
	Site 11	22%	100%	52%	41%
	Site 15	100%	100%	46%	62%
	Site 18	100%	100%	47%	57%
Curvilinear	Site 2	66%	6%	8%	0%
	Site 13	100%	100%	-19%	11%
	Site 21	100%	100%	83%	86%
Tangent	Site 3	-1%	-11%	-99%	-156%
	Site 8	74%	10%	-18%	5%
	Site 9	-56%	100%	-52%	24%
	Site 16	-57%	100%	-591%	-
	Site 19	-5%	-93%	-171%	-67%
	Site 20	-176%	100%	-349%	-67%
Curvilinear with junction	Site 5	66%	100%	30%	18%
	Site 12	100%	-44%	-5%	11%
	Site 14	-8%	3%	-69%	-31%
	Site 17	13%	100%	-74%	-40%

Referring to the definition of accident reduction factor (ARF) it is clear that a negative number denotes an increase in the number of accidents after the treatment.

Moreover, by means of comparison, the simple before-after analysis was carried out. Table 3 shows only the results relating to all the accidents because the high recurrence of zero target accidents in the after period made the calculation of θ insignificant for these cases.

The comparison between the simple and the Bayesian methods shows how the former tends to overestimate the efficiency of treatments compared to the latter (figure 1). In general, this can be attributed to the regression to the mean phenomenon.

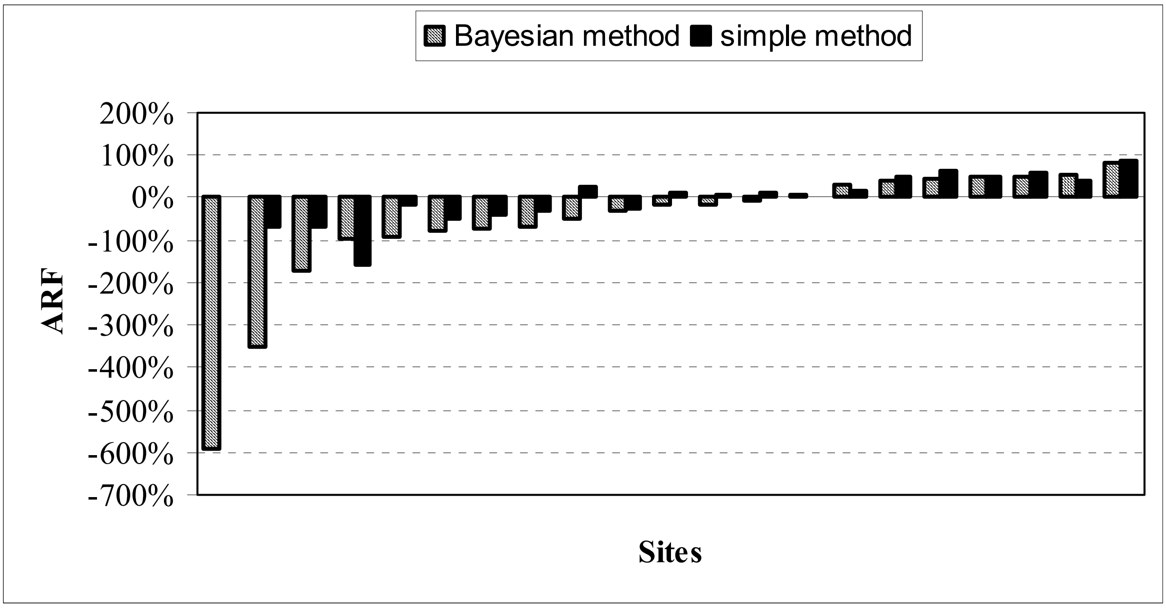

FIGURE 1: Comparison of ARF values obtained with the Simple and the Bayesian methods for the investigated sites.

Thus, referring to the results carried out with the Bayesian method it can be seen how, with respect to the total number of accidents, in only 38% of cases (8 sites) was there a reduction in the number of accidents after the treatment (figure 1), the percentage of positive values became 57% with respect to the out-of-control and hitting-an-obstacle accidents (figure 2).

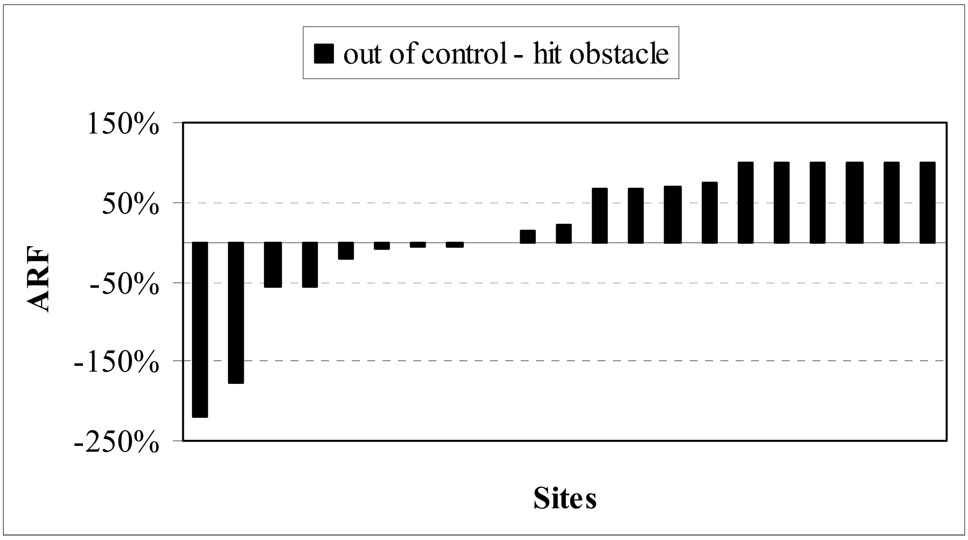

FIGURE 2: ARF values of target accident types for the investigated sites.

Instead, if only the wet pavement accidents are analysed, there is a an improvement in terms of safety in 86% of the sites (figure 3).

FIGURE 3: ARF values of target wet pavement for the investigated sites.

Evaluation of the Expected Accident Reduction Factor for Resurfacing

Having a sample site on which the same treatment was carried out, it is possible to use the results of the before and after analysis to determine an expected accident reduction factor ARF for that type of intervention.

The problem of estimating the expected accident reduction factor can be solved with statistical inference methods. These methods utilise the information contained in a sample of the population for drawing conclusions. In practice, sample data are used to compute a number that is a reasonable value of the true mean and that is called point estimate. The precision of a parameter estimate can be evaluated with a confidence interval.

The data related to all the sites or to group of sites with similar features can be aggregate with the aim to obtain overall statistics on the effectiveness of the treatments.

Aggregations of sites was obtained taking into account horizontal alignment (Tangent or Curvilinear) and presence of at grade junctions (with junction or without junction). Also all accidents or only target accidents were considered in the analysis.

In this way the analysis can be performed with the same formula defined in the EB method previously discussed, using the sum of the observed, predicted and variance of the predicted after period accidents and then calculate the estimate of effectiveness using these numbers for more sites together.

The results obtained are shown in Table 4 and Figure 4.

TABLE 4 Expected Accident Reduction Factor for Resurfacing Treatment

Site Typology	Target accidents								All accident types			
	Out of control with no collision, Hit permanent obstacle, Hit temporary obstacle				Wet pavement							
	mean	std. dev.	85% confidence interval		mean	std. dev.	85% confidence interval		mean	std. dev.	85% confidence interval	
			lower	upper			lower	upper			lower	upper
with junction	**2%**	32%	48%	-44%	**69%**	13%	88%	51%	**-5%**	14%	16%	-25%
without junction	**32%**	31%	76%	-12%	**35%**	36%	87%	-16%	**-59%**	37%	-5%	-113%
tangent	**-8%**	36%	44%	-61%	**57%**	17%	82%	32%	**-13%**	16%	10%	-35%
curvilinear	**24%**	35%	74%	-26%	**70%**	18%	96%	44%	**-44%**	33%	4%	-91%
total sites	**-8%**	29%	34%	-50%	**52%**	17%	76%	28%	**-42%**	17%	-17%	-66%

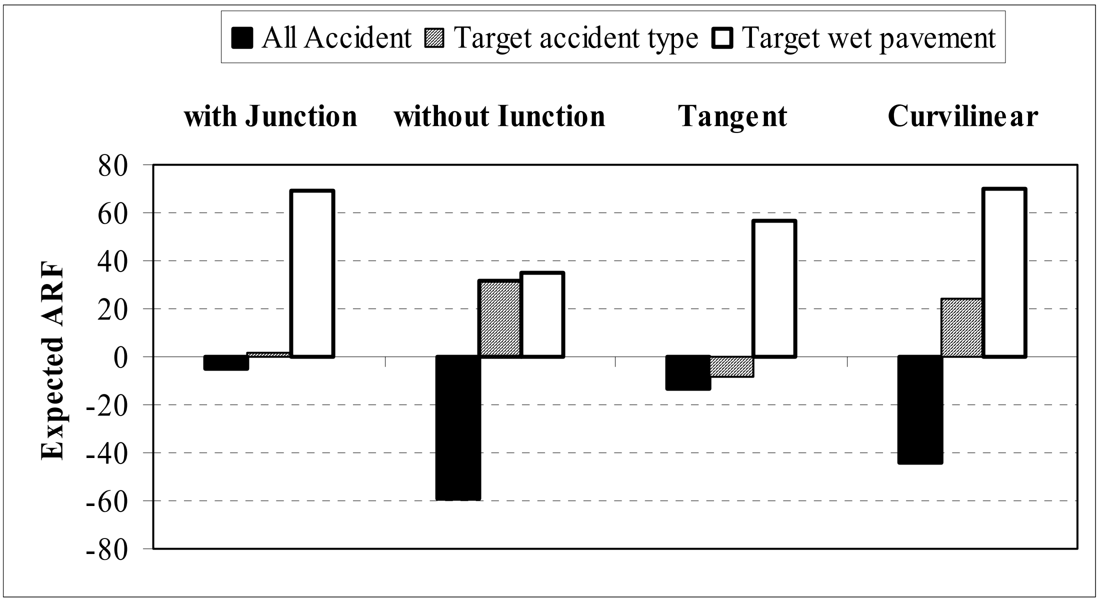

FIGURE 4 Expected ARF values for different accident type and site typology.

In the table the values of mean ARF, standard deviation and lower and upper limits with a 85% level confidence, are reported for the different site typologies and accident types considered in the research.

On the basis of the results obtained some considerations can be carried out. In general, only with respect to wet pavement accidents there is an absolute positive effect of the resurfacing. The ARF is positive for every site typology aggregation with higher values in the case of presence of Junction (+69%) and of curvilinear alignment (+70%). Instead, an evident negative effect (-42%) was detected when total sites and all accident types are considered all together. Although, this value means an increase of 42 % in the total number of accident after a resurfacing, a decrease in the severity of accident was observed too. In fact, after the treatment the number of fatalities per accident changed from 0.075 to 0.045.

For the other site and accident typology aggregations, most of the results are not significant since the estimate of effectiveness confidence intervals include a value of 0. This results highlight the dispersion of the results showed also by figure 2.

CONCLUSIONS

Before-and-After studies permit the evaluation of the safety effectiveness of an intervention comparing the accidents observed after treatment with the number of expected accidents for that site, if treatment had not been carried out.

To estimate the expected number of accidents in the absence of treatment many procedures have been presented in literature. Based on a literature review and on previous studies, in the present research the Bayesian method was used to correct the regression to the mean phenomenon. The comparison between the simple and the Bayesian methods confirmed how the former tends to overestimate the efficiency of treatments compared to the latter.

The results carried out showed generally an average increase of 42 % in the total number of accidents after the resurfacing but also a decrease in the severity of accident. A significant decrease in the number of accident after the treatment was observed only for wet pavement conditions especially in sites with junction or with curvilinear sections. In general, where junctions are present the greatest benefits are found.

These results confirm that a pavement resurfacing treatment can produce beneficial effects on safety over all for the accidents that are more directly correlated to pavement adherence (Hauer,1994; NCHRP 2001)

In the other cases an increase in the number of accidents can be expected if a hazard not related to the pavement condition exists on the road. In fact, good surface characteristics, giving an improved quality of driving and visual contrast of the road signs on the new surface, determine a driver's perception of increased safety. This leads the user to drive faster and to adopt more aggressive behaviour with a possible increase in the objective risk (Cafiso, 2000). So that, it is necessary to adopt other safety improvements to avoid a worsening of the accident situation.

REFERENCES

Cafiso S, A. Di Graziano (2000), Influence of macrotexture, skid resistance and surface unevenness on driving safety. PIARC, IV International Symposium on Pavement Surface Characteristics of roads and Airfields. Nantes.

Cafiso S., Augeri M.G. (2001), Before-and-after analysis methods to evaluate the safety effectiveness of road maintenace treatement, Strade e Autostrade journal, marzo-aprile.

Elvik, R. (2000), The importance of confounding in observational before-and-after studies of road safety measures, Accident Analysis & Prevention, Vol. 34.

Hauer, E. (1994), Effect of resurfacing on safety of two-lane rural roads in New York State. TRB n. 1467.

Hauer, E. (1997), Observational before-after studies in road safety Pergamon Press, Oxford.

NCHRP Impacts of resurfacing projects with and without additional safety improvements (2001). Research Result Digest n° 255, TRB, Washington D.C.

Shen, J., Gan A. (2003), Development of crash reduction factors: methods, problems and research, 82th Annual Meeting of the Trasportation Research Board.

Yuan F., Ivan J., Davis C., Garrick N. (1999), Estimating benefits from specific highway safety improvements: phase 1 – feasibility study, 78th Annual Meeting of the Trasportation Research Board, Washington, D.C..