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ABSTRACT

This study focused on safety performance of new pavement surface types. Open graded or coarse-textured roadway surfaces are advisable for high-speed, wet-weather traffic conditions. They provide drainage relief at the tire-pavement interface, reduce the steepness of the speed gradient, decrease the likelihood of hydroplaning, minimize splash and spray, reduce the glare from wet pavements, and improve high-speed skid resistance. Before-and-after comparisons using historical collision data from California Traffic Accident Surveillance and Analysis System (TASAS) were conducted to assess the safety performance of three types of experimental pavement: open-graded asphalt concrete (OGAC), groove pavement (GP), and rubberized open-graded asphalt concrete (R-OGAC) projects implemented in recent years. Because these new types of pavement surfaces are expected to improve drainage, wet pavement related collisions were considered target collisions and analyzed in the before-and-after study. Our findings indicate that resurfacing with OGAC significantly decreased the number of wet-related collisions. However, no significant conclusions were drawn from the results of resurfacing with GP and R-OGAC, due to the lack of sufficient data. While further research is needed, findings from this current study suggest that new pavement types such as OGAC can improve the safety performance of roadways.

INTRODUCTION

Wet pavement-related collisions represent a significant concern in traffic safety. (*1*) According to a U.S. study of collision data in 2001, more than 22 percent of collisions nationwide were weather-related. Previous studies have investigated the relationship between wet pavement conditions and collisions on roadways. A 1990 synthesis report by NCHRP, directed at the subject of wet-pavement accidents, summarized the research findings from earlier studies. (*2*) Research has indicated that a major factor in wet-pavement accidents may be the lack of adequate friction between the tire and the pavement. Another study by NTSB used the fatal accidents from FARS to evaluate the wet-pavement exposure. (*3*) The NTSB concluded that the wet-pavement accidents occur 3.9 to 4.5 times more than might be expected from data averages. Andrey, J. et al. (*4*) showed that inclement weather increased travel risk in six mid-sized Canadian cities and induced a chronic danger for travelers in Canada. They found that generally, precipitation is related to an increase in traffic collisions and an increase in related injuries. Black and Jackson (*5*) elaborated on several scenarios related to wet weather collisions.

Improving the safety of the roadway has been a priority for the California Department of Transportation (Caltrans), and to this end, Caltrans has implemented different types of pavement materials to improve the drainage system. These materials include a higher percentage of void space in the pavement itself. Due to the improvement of the drainage system, water will seep through these voids more rapidly, which is expected to reduce wet pavement related collisions. There are three different types of pavement considered in this study. The first is Open Graded Asphalt Concrete (OGAC), which contains a high percentage of air voids. The second is Groove Pavement (GP), which has longitudinal or transverse cuts on its surface. The last one is Rubberized Open Graded Asphalt Concrete (R-OGAC), which is asphalt modified by the incorporation of rubber which helps to increase the fatigue resistance of asphalt.

A National Cooperative Highway Research Program (NCHRP) synthesis of practices highlighted the benefits of open-grade surface (*6*). Open graded or coarse-textured roadway surfaces are advisable for high-speed, wet-weather traffic. They provide drainage relief at the tire-pavement interface, reduce the steepness of the speed gradient, decrease the likelihood of hydroplaning, minimize splash and spray, reduce the glare from wet pavements, and improve high-speed skid resistance. The skid number increases as the texture depth increases, and the wet-pavement accident rate diminishes as the skid number increases.

The objective of this study is to identify and analyze before-and-after historical collision data at the operational test sites where new types of pavement, including OGAC, GP, and R-OGAC, have been installed in order to quantify the effectiveness of the safety performance of similar pavement improvements. For this purpose, before-and-after comparison of wet-related collisions was conducted, and we referred to Hauer's (*7*) method to predict the number of wet-related collisions under the assumption of no improvement, and then compared the actual number of wet-related collisions after the improvement.

This paper is organized as follows. The study sites and data used are presented in the second section. The third section describes the before-and-after comparison method used in this study. The fourth section presents comparison and interpretation of the results. The final section presents conclusions and future research.

STUDY SITES AND DATA

Three different types of material were implemented in 21 sites throughout California. Figure 1 and Table 1 show where each of the different types of pavement was implemented. Thirteen of the implemented sites used OGAC, four of them used GP, and the remaining four used R-OGAC. The study period was between 1994 and 2005. Collision data from California Traffic Accidents Surveillance and Analysis System (TASAS), traffic volume data from Caltrans Traffic Data Branch, and hourly precipitation data at the nearest National Oceanic and Atmospheric Administration (NOAA) weather station were used for before-and-after comparisons.

To select the most appropriate weather station for each study site, all weather stations within the 20 miles of study sites were considered. The weather information included in the TASAS data was compared with the precipitation data from the weather stations. We chose the data from the weather station that best matched in the TASAS records, and using the weather station data, we were able to determine the number of rainy hours and quantify the exposure to precipitation and wet weather conditions.

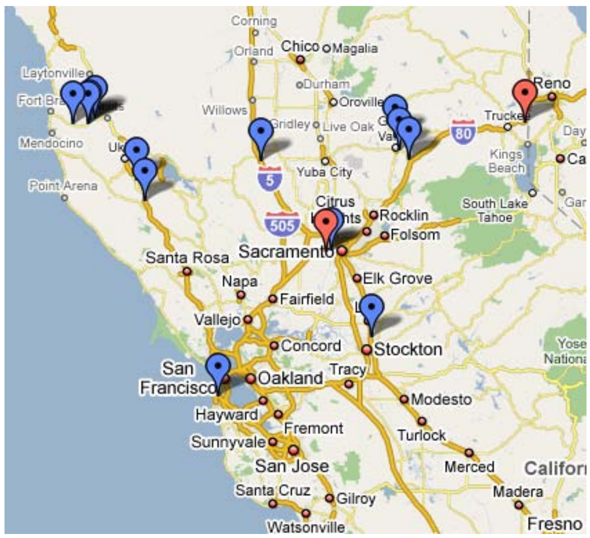

Figure 1 Study Sites

Table 1 Study Sites

Type of Pavement	The Number of Studied Sites
OGAC	13
GP	4
R-OGAC	4
TOTAL	21

METHODS

As mentioned above, the countermeasure is expected to be effective in reducing wet-related collisions. Figure 2 shows before-and-after comparisons of wet-related collision rates at study site 6. Although the dry collision rate did not change significantly, the wet collision rate decreased dramatically. This is because improved drainage has a beneficial effect on reducing the collision rate only when it rains. Therefore, the analysis was conducted by comparing the wet-related collisions before and after the countermeasure was implemented.

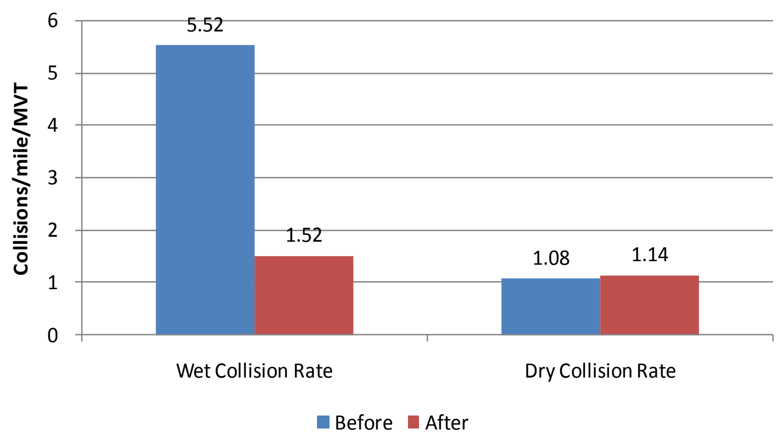

Figure 2 Before-and-After Comparison of Wet-Related Collision Rates at Study Site 6

For the before-and-after comparisons, collision data from two years before and two years after implementation was used. To allow fair comparison for the before and after periods of a pavement project, we used study periods of the same number of years to achieve a certain degree of data stability. Because the minimum number of years for which data was available was two years, we chose this time length for all study sites.

Wet collision data for rainy hours were used as target collision rates and then compared. Rainy hours were defined as the sum of the number of hours of rainfall and six hours after precipitation ended. This is due to the lingering effects of precipitation. When the occurrence time of wet collisions from the study sites were compared with the hours of precipitation, a considerable portion of them occurred within six hours following rainfall. This might be due to wet pavement following precipitation. Based on the relative timing, it was assumed that wet collisions could be affected by the exposure to rain within six hours after the rain ended.

To conduct statistical tests on comparisons, we referred to Hauer's method (*7*). This method compares the predicted and the observed number of collisions. Let π be the predicted number of collisions under the assumption of no improvement and λ be the observed (actual) number of collisions after improvement. The predicted number of collisions, π, can be predicted by two different methods. The first one uses only the information about treatment sites and the second is to use the information from comparison groups. Both methods were applied to our study. The distribution of the number of collision is assumed as Poisson.

Before-and-After Studies of Treatment Sites

Using the first method, we can predict the number of collisions, π, was predicted based on the information from treatment sites prior to improvement. If nothing changes at all, π will be same as the observed number of collisions before the improvement, κ. However, AADT and rainy hours change and have an effect on the number of collisions. Therefore, we need to adjust these factors. By adjusting rainy hours and AADT, π can be estimated as follows:

$$\pi = r_d r_{tf} \kappa$$

Where π: predicted number of collision after the improvement under the assumption of no improvement;

κ: observed number of collisions before improvement;

r_d : adjustment factor for rainy hours;

r_{tf} : adjustment factor for AADT.

Adjustment factors for rainy hours are simply the ratio of before and after rainy hours since the wet collision rate is proportional to the duration of wet pavement conditions, represented here by 'rainy hours.'

$$r_d = \frac{Rainy\ hours_{after}}{Rainy\ hours_{before}}$$

In addition, the AADT correction factor, r_{tf} can be expressed as follows:

$$r_{tf} = \frac{f(AADT_{after})}{f(AADT_{before})}$$

The AADT correction factor is not a linear function of AADT, because AADT is not proportional to the number of collisions and the relationship between AADT and the expected number of collisions is non-linear. In this study, the function was assumed as $AADT^{0.8}$ which is generally accepted (*7*).

Before-and-After Studies Using Comparison Groups

Even if the collision rate is significantly reduced after the improvement, additional factors could be responsible for collision reduction. For example, if safety education was improved, and wet-related collisions reduced not only at the treatment site but also at neighboring sites, then we cannot state conclusively that is the reduction was due to the implementation of the new pavement type. Therefore, the neighboring sites, which are called comparison groups, need to be considered. The second method for predicting the number of collisions after the improvement under the assumption of no improvement is by using the information collected from comparison groups. Comparison groups are the two sites adjacent to the treatment sites of the same length as the treatment sites. Figure 2 shows the description of comparison groups. If the treatment site was located in the end of a freeway, only one adjoining comparison site was considered for comparison.

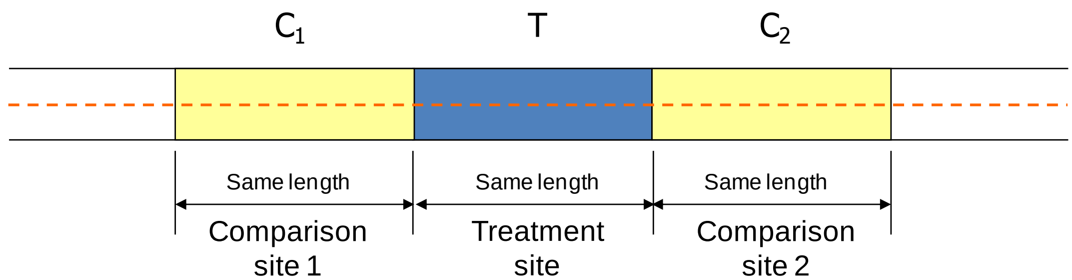

Figure 3 Description of Comparison Groups

While analyzing the comparison group information, two assumptions were made. First, the factors that affect safety have changed from the 'before' to the 'after' period in the same manner at both the treatment site and the comparison site group.. Second, this change in the factors influences the safety of the treatment site and the comparison site group in the same way. Under these assumptions, we predicted the expected number of collisions with a correction factor based on the comparison group by adjusting the comparison ratio, meaning that the ratio of the expected 'after' number to the expected 'before' number of target accidents. The following formula explains the prediction process:

$$\pi = r_c \times k = \frac{(C_1+C_2)_{after}}{(C_1+C_2)_{before}} \times k$$

Where π: predicted number of collision under the assumption of no improvement;
k: observed number of collision before improvement;
r_c : comparison ratio;
C_1= the number of collisions at comparison site 1;
C_2= the number of collisions at comparison site 2.

RESULTS OF COMPARISONS

Before-and-After Studies On Treatment Sites

The results of the before-after comparisons of three pavement types, OGAC, GP and R-OGAC, using only the information from treatment sites is shown in Figure 4 and Table 2. The first red bar represents the total sum of the predicted number of collisions under the assumption of no improvement at all thirteen OGAC sites, and the blue bar represents the observed number. The predicted number of collisions was 59 per two-year period, whereas the actual collision rate was 42 per two-year period. This means that the collision rate decreased by about 17 over a two-year period in OGAC-surfaced sites.

Based on these pooled values, we conducted statistical tests using only the information from treatment sites. We have two measures of comparison—the first is ratio, which represents the percentage increase or decrease in the collision rate. The ratio can be calculated using the following formula:

$$\text{Ratio} = \theta = \pi/\lambda$$

Therefore, ratio less than one means that the collision decreased after implementation. The second measure is difference, as show below:

$$\text{Difference} = \delta = \pi-\lambda$$

A difference of less than zero indicates that the collision rate decreased. We compared the two measures because some practitioners might be interested in ratio (e.g., collision reduction factor), whereas others might be interested in the actual numerical reduction in collisions or deaths.

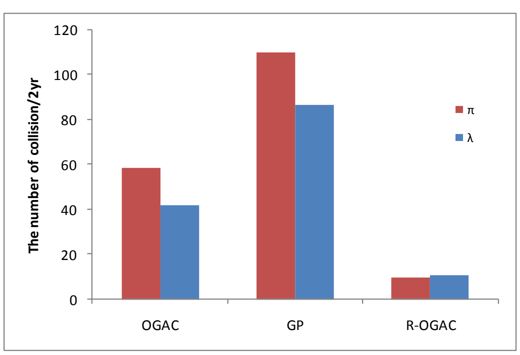

Figure 4 Comparison of the Number of Collisions (Method 1)

Table 2 Comparison of the Number of Collisions (Method 1)

Types of pavement	OGAC	GP	R-OGAC
The number of studied sites	13	4	4
π (Predicted)	58.91	110.17	9.82
λ (Observed)	42.00	87.00	11.00
VAR(π)	27.94	89.88	2.84
VAR(λ)	42.00	87.00	11.00

Table 3 Statistical Test (Method 1)

Types of Pavement	OGAC	GP	R-OGAC	Types of pavement	OGAC	GP	R-OGAC
The number of studied sites	13	4	4	The number of studied sites	13	4	4
θ= π/λ	0.71	0.78	1.09	δ= π-λ	16.91	23.17	-1.18
STDV(θ)	0.13	0.11	0.37	STDV(δ)	8.36	13.30	3.72
95% Confidence interval	(0.46,0.96)	(0.57,1.00)	(0.35, 1.82)	95% Confidence interval	(0.2,33.6)	(-3.4, 49.8)	(-8.6,6.3)
Statistical significance at 95% confidence level	Decreased	Decreased	Not significant	Statistical significance at 95% confidence level	Decreased	Not significant	Not significant

Table 3 shows the results of statistical tests for the three different pavement types. The collision rate was reduced to 46-96% of the 'before' level at the 95% confidence level the pavement was resurfaced with OGAC, and to 57-100% when resurfaced with GP. These results are statistically significant, but due to the availability of only four sites for sites resurfaced with R-OGAC, there are no significant results for R-OGAC. Based on the difference test as shown in Table 3, collisions were decreased by 0.2 to 33.6 wet collisions per two-year period at OGAC sites—a statistically significant reduction. However, conclusions cannot be drawn for GP and R-OGAC due to the insufficient number of study sites.

Before-and-After Studies Using Comparison Groups

The pooled values of π and λ by pavement type are shown in Figure 5 and Table 4. For example, the predicted number of collisions in all thirteen OGAC sites was 68 collisions per two-year period, whereas the actual number of collisions was 42 collisions per two-year period. This means collisions decreased due to the improvement.

Using these pooled values, the same statistical test was conducted and the result is given in Table 5. Based on ratio test, the collision rate as reduced to 27-90% of the 'before' level at the 95% confidence level when resurfacing the pavement with OGAC. In addition, implementation of GP decreases the number of collisions to 12-88% of the 'before' level significantly. However, we don't have significant results from R-OGAC due to the lack of sample sites. Results from the difference test were insignificant due to the relatively large variance in the number of collisions in comparison groups. However, implementation of OGAC decreased wet collisions by 26 over a two-year period. Even if not significant, this is still a large reduction.

To summarize, by adjusting for changes in comparison sites resurfacing with OGAC significantly decreased the number of collisions by 10-73%. Resurfacing with OGAC decreased the number of collisions by 25.86 wet collisions over a two-year period, but was not proven statistically significant. The limited number sample sets for GP and R-OGAC prevented any conclusions about their effectiveness to be drawn.

The reason that the statistical test based on ratio is different from that based on difference is that the number of wet collisions is relatively small. Due to the small number of collisions, the ratio of reduction is relatively bigger than the difference of reduction.

The results are fairly consistent with the results of the comparisons with the information from treatment sites. The only difference in the statistical conclusion is the comparison of the number of collisions at OGAC sites, which is due to large variations in the number of collisions at the comparison groups of OGAC study sites.

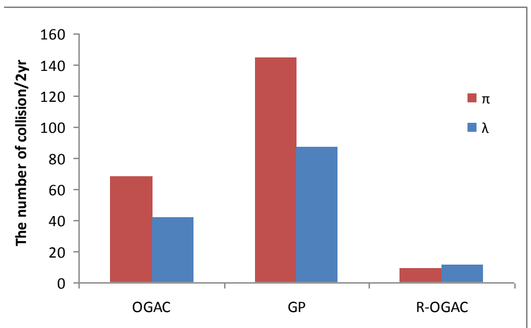

Figure 5 Comparison of the Number of Collisions (Method 2)

Table 4 Comparison of the Number of Collisions (Method 2)

Types of Pavement	**OGAC**	**GP**	**R-OGAC**
The number of studied sites	13	4	4
π (Estimated)	67.86	145.05	8.48
λ (Actual)	42.00	87.00	11.00
VAR(π)	255.24	4208.22	14.91
VAR(λ)	42.00	87.00	11.00

Table 5 Statistical Test (Method 2)

Types of Pavement	**OGAC**	**GP**	**R-OGAC**	**Types of pavement**	**OGAC**	**GP**	**R-OGAC**
The number of studied sites	13	4	4	The number of studied sites	13	4	4
θ= π/λ	0.59	0.50	1.07	δ= π-λ	25.86	58.05	-2.52
STDV(θ)	0.16	0.19	0.49	STDV(δ)	17.24	65.54	5.09
95% Confidence interval	(0.27,0.90)	(0.12,0.88)	(0.10, 2.05)	95% Confidence interval	(-8.6, 60.3)	(-73.0, 189.1)	(-12.7, 7.7)
Statistical significance at 95% confidence level	Decreased	Decreased	Not significant	Statistical significance at 95% confidence level	Not significant	Not significant	Not significant

CONCLUSION

The main objective of this study is to identify and analyze before-and-after historical collision data at the operational test sites where new types of pavements have been installed in order to quantify the effectiveness of the safety performance of similar pavement improvements. Two methods of comparison were used. The first used the information from treatment sites. AADT and the number of rainy hours at the treatment sites were analyzed to refine the comparisons. The second measurement method used the information from both treatments sites and comparison groups.

Based on the results of the second method, resurfacing with OGAC appeared to significantly decrease the number of collisions by 10–73%. Resurfacing with OGAC decreased the number of collisions by 25.86 wet collisions per two-year period but was not proven statistically significant. Each of the GP and R-OGAC sites were analyzed offered an insufficient sample set to make it possible to draw any conclusions.

Our findings indicate that resurfacing with OGAC significantly decreased the number of wet related collisions. Unfortunately, we do not currently have sufficient data to draw any significant conclusions for resurfacing with GP or R-OGAC. This would be a fairly straightforward extension of our study and could be conducted by including additional sites in our analysis.

A Collision Reduction Factor (CRF) can be established for different pavement types if there are relatively small confidence intervals for the amount of collision reduction. The process can be refined by taking into account other factors, including location (urban or rural), and roadway type in order to establish collision reduction factors for different pavement types. However, it is very important to obtain additional sample sites for all pavement types, especially GP and R-OGAC.

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