AN ASSESSMENT OF SAFETY AT SIGNALIZED INTERSECTIONS POST RESURFACING

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ABSTRACT
Crash records for a sample of signalized intersections have been analysed to assess the effect of surface treatment. Analysis of crash data (all types and severity levels) for 3–5 years before and after resurfacing year showed a reduction in rate. Effectiveness of treatment in achieving statistically significant reduction in crashes was confirmed by Empirical Bayes (EB) approach. Overall trends of crash frequency before and after treatment against surface condition in terms of roughness, rut depth and skid resistance were also investigated. The results showed that the trend of crash rate correlates positively with roughness and negatively with skid resistance and rut depth. This trend was true for both before and after crash data. Time of day and moisture condition of the surface proved to strongly influence crash frequency with wet surface during night-time being associated with lower frequency than dry surface at daytime.
Keywords: crash frequency, crash rate, Empirical Bayes, roughness, rutting, safety effectiveness, signalized intersection, skid resistance.

1 INTRODUCTION

Understanding the contribution of factors that affect performance of signalized intersections is important for addressing safety concerns. Some of these factors are related to the road itself. Such factors include traffic volume and composition, speed, geometry, condition of line marking and signage, signal phasing, light condition and surface condition. It is believed that adequate level of pavement condition does not only improve operational performance of signalized intersections but also results in considerable reduction in crashes. The study reported herein involves a before and after study of crash data at signalized intersections sites that were subject to resurfacing with a thin asphalt layer. These sites consist of granular pavements (crushed rock bases and sub-bases) with thin asphalt surfacing and located in a metropolitan region of Australia. The objectives of study are the following:

1. To better understand the effects of pavement condition parameters on crash rates at signalized intersections. They include surface roughness (in terms of the International Roughness Index (IRI)), rutting (in terms of rut depth (mm)) and skid resistance (in terms of sideway friction coefficient (SFC)). This is in addition to situational factors including light condition and surface moisture condition.
2. To evaluate safety effectiveness of improvements in pavement condition due to surface treatment.

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2 BACKGROUND

Provided in this section is a summary of findings from past published studies on safety effectiveness of resurfacing and the effects of the condition parameters stated above on crash rates. These studies involved using different methodologies and cover different locations (intersections and road links) and operating environments (rural and urban). The summary of findings is presented in Table 1, from which the following can be inferred:

- Generally, resurfacing is effective in reducing crash occurrence but varies in extent by crash type and severity. In few cases there has been an increase in crashes which is related to increased speed with the new surfacing.
- No clear relationship between roughness with crash occurrence at signalized intersections.
- Deep ruts may contribute to crash occurrence particularly in wet nights.
- Improving skid resistance has a great impact on crash frequency reduction.
- More crashes occur during the day than at night and night crashes in lit streets are less frequent than in unlit streets and associated with lower severity.

3 ASSESSMENT DATA AND APPROACH

3.1 Site selection

Crash data for the study area was available between 2000 and 2013. For this study, all signalized intersections that were subject to resurfacing during the period of 2005–2010 were identified. This period was selected as it is the period over which relevant condition data (roughness and rutting) was available for one year before and after treatment years. Further, within this period, crash data was available for each intersection over 5 years before and a minimum of 3 years after treatment year (NZTA [1]). The final set of treated sites had a sample size of 136.

Table 1: Summary of findings from published literature.

Reference	Findings
Hauer et al. [2]	Non-intersection crashes increased by 21% for projects involving only resurfacing but safety improved for projects where additional improvements accompanied the resurfacing.
Abdel-Aty et al. [3]	Total number of crashes increased by 62% at the resurfaced sites. However, the rear-end crashes reduced by 0.83% and severe crashes reduced by 4.63%.
Pardillo Mayora and Jurado Pina [4]	Resurfacing significantly reduced wet-pavement crash rate by an average of 68%.
Zeng et al. [5]	Resurfacing treatment was significant in reducing fatal and injury crashes by 26% but was not effective in reducing total crash frequency.
Chan et al. [6]	Crash rate increased with IRI and that this was more pronounced in wet weather conditions and at night than in dry weather conditions and during daylight.
Cairney and Bennett [7]	High correlation between roughness and crash occurrence on road segments.

Larson et al. [8]	No strong relationship between wet or total crashes and average IRI for signalized intersections.
Cairney and Bennett [9]	No relationship between roughness and crash occurrence at urban signalized intersections.
Tighe et al. [10]	Single-vehicle crash rate decreased with an increase in road roughness but multiple-vehicle crash rates increased.
Cairney et al. [11]	Crash risk related to rutting increased in the deepest rutting sites only.
Chan et al. [6]	Rut depth did not affect crash prediction models significantly except for night and weather-related crashes.
Candappa et al. [12]	A reduction of about 44% in casualty crashes when skid resistance was improved with surface treatment.
Saplioglu et al. [13]	There is a significant reduction in crash rates as skid resistance increased.
Simpson and Eng [14]	A reduction in number of crashes of 39% in areas treated with high skid resistant surfaces.
Pardillo Mayora and Jurado Pina [4]	A significant decrease in crash rates as skid resistance increases in both wet and dry pavement conditions. They reported an average of 68% reduction in wet-pavement crash rate after resurfacing.
Khattak [15]	54.9% of crashes occurred during the day at both morning and evening peak hours. Also that only 10.8% of crashes was related to night with unlit street condition and 4.9% on lit street condition.
Yan et al. [16]	Daytime crashes constitute 71.7% and night-time crashes 28.3% of total crash frequency.
Wang and Abdel-Aty [17]	Crashes occurred at night with street lights were associated with lower crash injury level.
Hollo and Kajtar [18]	A strong correlation between crashes occurring during the night with wet condition than crashes during the day and dry conditions.
Golob and Recker [19]	Rear-end crashes are likely to be related to day-dry condition and crashes involving more than one vehicle are likely to be related to wet surface condition.

This study is considered fully controlled as the same intersections were used before and after treatment so the only variation was related to surface condition. All other road-related factors that may affect crash occurrence including speed limit remained unchanged. Line marking condition has also been checked and found to be in good condition before treatment and in new condition after. It is important to note that resurfacing treatments applied do not cover the whole intersection. They may cover the intersection centre and/or its approaches (immediate 200 m). The total length of treatment that was used in the analysis ranged between 100 and 500 m. Records of skid resistance data were only available for the period 2006–2011. This resulted in identifying only 57 out of the 136 sites with all condition data being available one year before and after treatment. It is important to note that the effect of the variation in traffic volumes for the years before and after treatment was controlled by using crash rates instead of frequencies when assessing the change in crash occurrence in trend analysis, however, crash frequency was used for evaluating the change by EB approach.

3.2 Data preparation

Crash data collected included all casualty crashes, i.e. covering all severity levels (fatal, serious injuries and other), type of crash (head-on, rear, etc.), light condition when they occurred (day or night), road surface moisture condition (wet or dry) and speed limit. To provide a balanced analysis, an equal period of crash data for before and after treatment for each intersection has been selected and the longest available period for each intersection (i.e. either 3, 4 or 5 years) has been used. Crash rates for each site, before and after treatment, were determined by dividing total traffic volumes covering the same period over which crash data is available by the total number of crashes. Crash rates are reported in terms of number of crashes per 10 million vehicles entering the intersection (10 MVE) (Austroads [20]). Traffic volume data used was in terms of annual average daily traffic (AADT) that used the section of road where the intersection site is located, along the approaches where crashes took place.

Surface condition data including roughness, rutting and skid resistance of the treated direction of each site was collected for one year before treatment year and one year after. Roughness is reported in terms of lane IRI (average of two wheel paths) in m/km and rut depth in mm for each 100 m segment. Data of skid resistance is collected for both wheel paths using sideways force coefficient routine investigation machine (SCRIM) and reported for each separately and their average in terms of sideways force coefficient (SFC) values, also for 100 m segments. Data documented by SCRIM is a positive integer equivalent to SFC*100.

For the analysis performed herein, data of each condition parameter for each site was averaged over a length of 500 m, covering the intersection centre and a maximum of 400 m of its approaches. The selected 500 m section is along the leg that includes the treated section and location of crashes. It is important to note that treatments of pavements at intersections and their approaches are currently triggered by surface distress ratings, referred to as surface inspection rating (SIR), regardless of roughness level. SIR of an asphalt surfacing is a composite index of the ratings for cracking, stone loss, texture loss, patching, and deformation (VicRoads [21]).

3.3 Assessment approach

The effects of the three pavement condition parameters on crash rates were assessed using trend analysis using data of 136 sites for roughness and rutting and 57 sites for skid resistance. This was applied to casualty crashes only in both before and after the year of surface treatment and considering relevant situational factors.

The evaluation of safety effectiveness of improvements in pavement condition of 136 treated sites was conducted using Empirical Bayes (EB) approach. The primary goal for EB technique is to compare observed crash data for before period with crash data in the after period for same site. The advantage of using EB over the other available approaches is that it accounts for regression to the mean (RTM) bias, traffic volume change through using safety performance function and time trend (Hauer et al. [22]). This can be done by comparing the expected number of crashes for the after period had the treatment not been implemented with the reported number of crashes during the after period. This is based on using reference sites with similar traffic and other site characteristics (Persaud and Lyon [23], Gross et al. [24]). The number of reference sites identified that have not been treated during the study period is 66. This assessment has been applied to total casualty crashes, high severity (fatality and serious injury) crashes and other injury crashes.

4 ASSESSMENT RESULTS AND DISCUSSION

4.1 Assessing the effect of pavement condition

The effects of changes in surface condition on intersection safety performance due to surface treatment are assessed here through observation of trends from graphs. For trend analysis, the data of each condition parameter has been divided into groups or categories, each covering a certain range. Crash rate that corresponds to a certain category is the average value of crash rates for all intersections with condition parameter that falls within that category. The variation in crash rates with surface roughness for both before and after treatment is presented in Fig. 1a. There is a clear positive trend where crash rate increases with roughness and that is true for both before and after treatment data in addition to that it is higher before treatment than after. Some of the sites after treatment are associated with relatively high roughness >3 m/km. The reason for this is related to the fact that roughness level is not considered in treatment selection so a thin layer of asphalt resurfacing might not fix all profile characteristics contributing to roughness. Additionally, not all 500 m sections have been treated and during

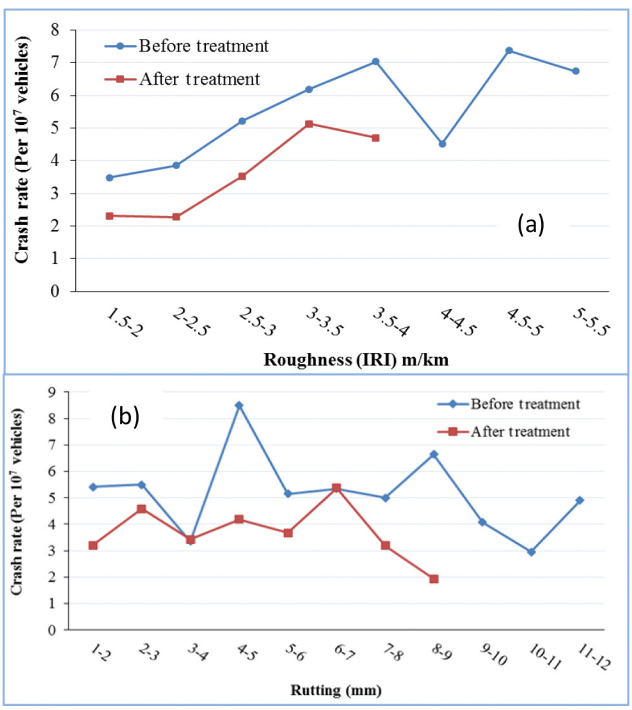

Figure 1: Casualty crash rate vs roughness (a) and rutting (b) categories.

the three years including the year of treatment and the years before and after, roughness of the untreated sections would have increased.

The crash rates associated with different rutting categories are also presented in Fig. 1b. The overall trend for crash rate with rutting categories seems negative, indicating lower crash rates where deeper ruts exist. This is true for both before and after treatment data with the only difference; that is, the first includes deeper ruts and higher crash rates than the second. The negative trend could be related to the fact that drivers slow down and are more alert when they see deep ruts hence reducing crash occurrence.

Additionally, it has been observed that regardless of roughness level or rut depth, crash rates vary significantly with time of day and surface moisture condition. Crash frequency during the day/dry surface is higher than at both night/wet and dry surfaces as can be noticed in Fig. 2. This could be related to higher traffic movements during daytime and dry conditions. There is no results for crash type in the paper. The variation in crash rates with skid resistance in terms of SFC, for both before and after treatment, is presented in Fig. 3 for wet and dry conditions. The overall trend seems negative, indicating lower crash rates with higher SFC categories and that is true for both before and after treatment data except that it is clearer for after treatment. Other observations can be summarized as follows:

- For both data sets, crash rate in wet surface conditions is significantly lower than in dry surface, regardless of SFC values.
- After treatment, crash rate peaks at SFC of 0.5–0.55 and before treatment; it peaks at the same range and at a high SFC range of 0.6–0.65.
- For both dry and wet surface conditions generally smaller percentages of crashes are associated with very high SFC categories. Overall it seems that crashes occur at all ranges of skid resistances with varying frequencies.

4.2 Evaluating safety effectiveness

Data from the reference sites was used to develop safety performance function (SPF) using negative binomial (NB) regression (Gross et al. [24]). SPFs are mathematical models that predict crash frequency for similar sites based on traffic volume and other site characteristics. Traffic volume is considered the most important factor in crash prediction models. Hence, the SPF for this study is based on total traffic volume entering the nominated approach of

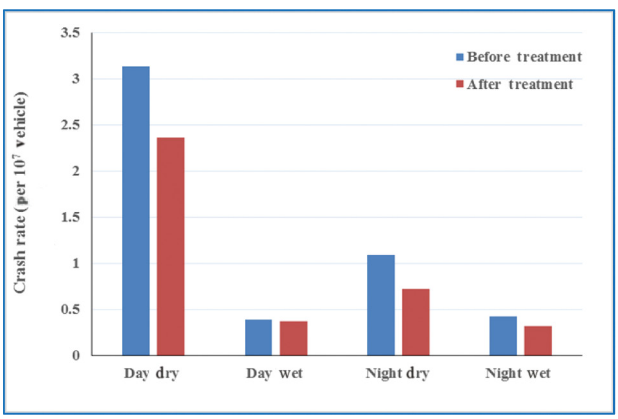

Figure 2: Distribution of casualty crash rates by time of day and surface moisture condition.

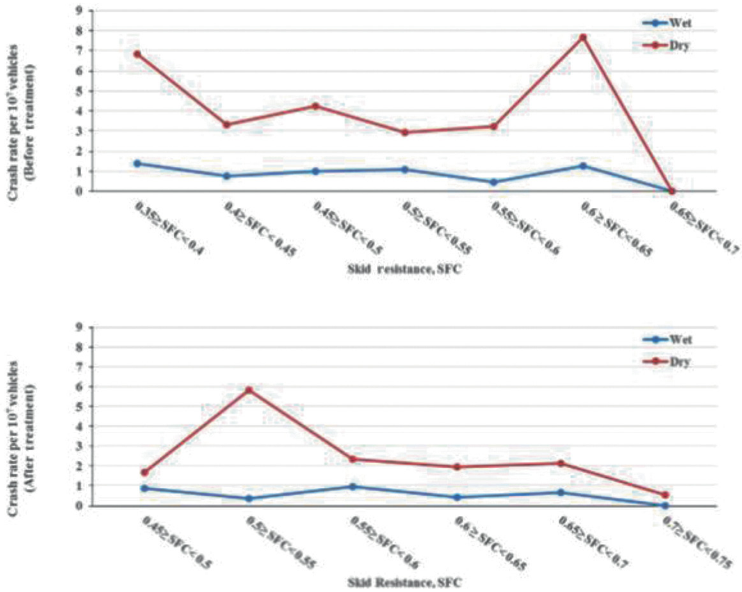

Figure 3: Casualty crash rate vs. skid resistance categories.

each intersection in a reference group. By using relevant information (crash frequency and traffic volume) from both treated and reference sites, the expected number of crashes at treated sites can be estimated. The detailed procedure of EB method described in Highway Safety Manual [25] has been followed to evaluate safety effectiveness of pavement surface treatment, expressed in percentage change in crashes. The analysis was performed on three different crash severity levels including casualty, high severity (fatality and serious injury) and other injury crashes. Total crashes for each of these categories for treated and reference sites before and after treatment and average AADT are summarized below:

- AADT: treated (before 12865, after 13485), reference (before 13395, after 13865)
- Casualty crashes: treated (before 44, after 32), reference (before 31, after 28)
- High severity: treated (before 12, after 18), reference (before 11, after 10)
- Other injury: treated (before 36, after 22), reference (before 21, after 22)

Using generalized linear model (GLM), the SPF models for each crash category were developed and the models' coefficients were estimated, assuming negative binomial error distribution. The primary model form for all SPFs used in this study is presented in eqn (1):

$$\text{Nspf} = \text{Exp}\,(\alpha + \beta * \ln\,(\text{AADT entering})). \tag{1}$$

Total crash frequency for all severity levels of reference sites and average AADT over 5 years have been used in developing SPFs. A yearly crash prediction model is derived by dividing the 5-year model by 5 (Lord and Persaud [26]). Table 2 provides results of NB regression for developing SPF for all three crash severity levels. The results indicate that the parameters are significant at 95% confidence level. The dispersion parameters of 0.419, 0.357 and 0.418 for total casualty, high severity and other injury crashes, respectively, are greater than zero which indicates that the dependent variable (crash frequency) is over-dispersed in all three models.

Furthermore, the values of deviance of 1.224, 1.179 and 1.223 and Pearson chi square of 0.799, 0.984 and 0.827 for total casualty, high severity and other injury crashes, respectively, obtained from the goodness-of-fit criteria are close to the ideal value of one which supports the use of NB model.

Necessary yearly factors such as SPFs multiplier are applied to eqn (1) to account for time trend in EB approach as shown in eqn (2).

$$N_{predicted} = \text{Exp}\ (\alpha + \beta * \ln\ (\text{AADT entering})) * \text{Yearly factor}. \quad (2)$$

These SPFs multipliers were derived for different crash severity levels for each year before and after treatment and are estimated as the total number of observed crashes divided by total number of predicted crashes for a given year (Highway Safety Manual [25]) as shown in Table 3. To account for the difference in duration between before and after period at each intersection the adjustment factor (ri) was calculated as given in the Highway Safety Manual [25].

The overall results obtained from EB approach to evaluate safety effectiveness for pavement condition improvement following treatment are given in Table 4. For total casualty crashes evaluated in this study, the odd ratio (OR) or crash modification factor (CMF) is 0.819 with

Table 2: Results of SPF model development for all crash severity levels.

Crash severity	Total casualty	High severity	Other injury
Parameters	Estimated value (standard error)	Estimated value (standard error)	Estimated value (standard error)
Intercept	1.889 (0.23)	0.879 (0.25)	1.464 (0.23)
AADT entering	0.0000288 (0.0000149)	0.0000145 (0.0000163)	0.000034 (0.0000156)
Dispersion parameter	0.419 (0.09)	0.357 (0.13)	0.418 (0.11)
Deviance	1.224	1.179	1.223
Pearson chi square	0.799	0.984	0.827

Table 3: Applied yearly factors for all crash severity levels.

Before treatment					
Severity level	Year 1	Year 2	Year 3	Year 4	Year 5
Total casualty	1.55	1.58	1.38	1.49	1.48
High severity (F & SI)	1.45	1.48	1.04	1.04	1.10
Other injury	1.24	1.40	1.30	1.46	1.37
After treatment					
Severity level	Year 1	Year 2	Year 3	Year 4	Year 5
Total casualty	2.00	1.44	1.16	0.91	1.14
High severity (F & SI)	1.60	1.26	1.23	0.78	0.72
Other injury	1.75	1.17	1.00	0.72	0.76

Table 4: Results of safety effect evaluation by EB before–after study.

Parameters	EB results		
Crash severity	Total casualty	High severity	Other injury
Number of intersections	136	136	136
Total number of crashes observed in the after period (Nobserved, A)	1,010	341	667
Total number of crashes expected in the after period had the treatment not been implemented (Nexpected, A)	1,231.71	367.51	748.83
Treatment effectiveness in the form of odd ratio for all sites, OR	0.82	0.928	0.891
Var (Nexpected, A)	882.26	172.29	424.05
Unbiased estimate of treatment effectiveness, OR (crash modification factor, CMF)	0.819	0.927	0.89
Safety effectiveness = 100 * (1– OR)	18.1%	7.3%	11%
Var (OR)	0.00106	0.00362	0.000179
SE (OR) = $\sqrt{\mathrm{Var}}(\mathrm{OR})$	0.032	0.0602	0.0423
95% Confidence interval = OR * ± 1.96 * SE (OR)	0.76–0.88*	0.81–1.05 **	0.81–0.97 *
SE (Safety effectiveness) = 100* SE(OR)	3.2	6.02	4.23
Abs [Safety effectiveness/SE(Safety effectiveness)]	5.66*>2.0	1.21**<2.0	2.6*>2.0

* Significant at 95% confidence level.
** Not significant at 95% confidence level.

a standard error of 0.032. For high severity crashes, the OR is 0.927 with a standard error of 0.0602, and for other injury crashes, OR is 0.89 with a standard error of 0.0423. The OR is significant (less than 1) at 95% confidence interval of (0.76–0.88) for total casualty and (0.81–0.97) for other injury crashes. This means at least 95% certain that there is a reduction in crashes after pavement surface treatment (Gross et al. [24]). However, for high severity (fatality and serious injury) crashes the OR estimate of 0.927 is not significant at 95% confidence interval of 0.81–1.05 since it includes 1.0.

The absolute value of the measure, Abs [Safety Effectiveness/SE (Safety Effectiveness)], for total casualty and other injury crash categories is greater than 2.0 which confirms that the treatment effect is significant at the (approximate) 95% confidence interval (Highway Safety Manual [25]). These evaluation results suggest that there is a reduction in total casualty crashes by 18.1% with a standard error of 3.2%, and 11% with a standard error of 4.23% for other injury crashes. Furthermore, the results indicate that although there is a slight reduction in high severity (fatality and serious injury) crashes by 7.3% with standard error of 6.02%, the reduction is found to be not significant at 95% confidence interval with the absolute value of the measure, Abs [Safety effectiveness/SE (Safety effectiveness)] of 1.22 which is less than 2.0.

5 CONCLUSIONS

Assessment of how different pavement condition parameters affect crash rates at signalized intersections showed that for both before and after treatment crash rate increases with pavement roughness. However, with increased rutting a reduction in crash rate was observed. Furthermore, higher crash rates were observed during daytime and in dry surface than during night-time and in wet surface. The variation in crash rates with skid resistance for both before and after treatment indicated lower crash rates at higher SFC categories.

Results of EB approach revealed that treatment effect is significant at the 95% confidence interval in reducing total casualty crashes by 18.1% and other injury crashes by 11%. However, for high severity crashes the analysis showed that the reduction of 7.3% is not statistically significant.

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