ASSESSING THE IMPACT OF PAVEMENT SURFACE CONDITION ON THE PERFORMANCE OF SIGNALISED INTERSECTIONS

Submission Date: 08/12/2014

Word Count: 4554

Number of Tables: 2

Number of Figures: 4

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ABSTRACT

Signalised intersections are one of the most dangerous places on the road network as they carry a very high crash risk. This may be exacerbated by inadequate pavement surface condition. The main objective of this study was to assess the effect of pavement surface condition (in terms of skid resistance, roughness and rutting) at intersections and approaches on users’ safety. In particular, this paper studied the change in crash frequency for numerous signalised intersections before and after surface treatment. Around one hundred sites were selected based on historical crash incident data and pavement maintenance records. Pavement condition data was extracted for these sites one year before and one year after surface treatment. For all sites, a minimum of three years crash data was used before and after treatment. Reported in this paper are the findings of an assessment of the changes in crash rates, types and severity due to surface treatment. Overall, assessment of the effect of surface treatment revealed a statistically significant reduction in crash rates of 0.49 at 95% confidence level with a p value of 0.006, based on a paired t-test. Negative binomial regression analysis was performed using pavement condition data, traffic volume and speed limit as the predictor variables of crash frequency. The results showed that both traffic volume and the interaction between traffic volume and skid resistance were significant contributors to the crash occurrence. However, for after treatment no independent variable had a significant contribution to the crash occurrence.

INTRODUCTION

Although intersections represent a small part of an overall highway system, the risk of an accident is high due to greater conflict areas. Among these, signalised intersections are the most dangerous places on the road network. Using historical crash data for Melbourne in Victoria (Australia) over the years 2000 to 2013 it was found that 33,850 high severity crashes (involving fatality and serious injury) occurred at intersections. These include cross intersections, T-intersections, Y-intersections and multiple-leg intersections. Of these, 16% occurred at signalised intersections.

According to government reports (1), the application of different types of treatments to reduce the number of crashes and fatalities on Victorian roads has been extremely effective over the years. The efficiency of the Statewide Crash Black Spot Program in reducing casualties in crashes and improving efficiency of intersection treatment regarding crash reduction is a good illustration of specific treatment types for addressing crashes (1). However, where eliminating crashes is impossible, reducing the severity is of major focus. In this situation, the effect of other elements of the roadway system such as pavement condition should be considered. The main objective of this project is to study how pavement surface condition in terms of skid resistance, roughness and rutting of approaches at signalised intersections affect crash frequency. For a large sample of signalised intersections in Melbourne, crash data was used to study how the variation in pavement surface condition affects rate, severity and type of crashes using statistical analysis. The sample includes only intersections that were subjected to surface treatment to allow a before and after treatment analysis.
BACKGROUND

There is a substantial amount of research related to different surface condition parameters and their effect on the safety of signalised intersections. The application of different types of treatments to reduce the number of crashes and fatalities on Victorian roads has been extremely effective over the years. The efficiency of the Victorian Statewide Crash Black Spot Program in reducing casualties in crashes was assessed based on a study involving 804 sites (1). The program was proven to be efficient in decreasing all casualty crashes by nearly 35% at all treated sites for all treatment types and by 44.2% due to improved skid resistance. High skid resistance treatments have been placed at different locations to reduce crash occurrence and severity of some crashes. It is expected that providing long term skid resistance characteristics would result in achieving significant reduction in crashes (2).

A study carried out for 55 sites in the United Kingdom also evaluated safety improvement before and after resurfacing (3). Skid resistance data (SFC) and crash data was collected for two years before and three years after treatment. The authors classified crashes into weather related crashes (dry/wet) and skidding related crashes. The average number of crashes that occurred in wet pavement conditions decreased from eight to two and the average number of crashes related to skidding decreased from six to two. Another study conducted in Sydney (Australia) assessed the effects of surface frictional coefficient and wet sideways on crash occurrence (4). The study showed a reduction in crashes of 25% at 99% confidence level for all surfaces after treatment. This was based on data for three years before and 18 months after treatment. Another study carried out in Melbourne and Geelong (Australia), investigated the performance of roads with high skid resistance and in terms of effect on crash rate trends (5). Analysis of the data for before and after study indicated a decrease in the number of crashes by 39% in the treated area, confirming the advantage of the treatment.

The relationship between skid resistance and crashes has been evaluated by many researchers. A study reported in (6) showed that there is a significant reduction in crash rates as skid resistance increased. A crash model for skid resistance (SCRIM) and texture depth (SMTD) on a single carriageway was developed in a study carried out in the UK (7). The model demonstrated that an increase in skid resistance from 0.35 to 0.6 reduced the crash rates by 65%.

To examine the effect of pavement condition characteristics on crash frequency, a study reported in (8) focused on asphalt pavements in urban environment with a speed limit of 80 km/hr. The International Roughness Index (IRI) was used as a measure of pavement condition. It was found that the crash rate increased as the pavement condition deteriorated especially in wet weather conditions and at night as compared to good weather conditions during daylight. The probable explanation for this is that when the pavement surface is rough, the driver has more difficulty with the visibility of the road surface in adverse conditions which increases the likelihood of crash occurrence (8). Similar results were found in a South African study (9). Furthermore, an exploratory study of the relationship between surface characteristics and crashes was conducted on selected rural roads in the Victoria/Australia (10). The authors investigated the relationship between roughness and crash occurrence and reported the best relationship to be a polynomial function with $r^2$ value of 0.99. However, for urban signalised intersections in Victoria it was found that there was no relationship between roughness and crash occurrence (11). Also, in Sweden, the effect of pavement roughness on traffic safety was evaluated (12). The results of this study indicated that the higher the IRI the higher the crash rate. In addition, an increase in
crash rates at signalised intersections was found to be associated with an increase in pavement roughness due to the presence of rutting, shoving and corrugated road surface (13).

Rutting has a significant effect on safety largely due to the increased potential of hydroplaning due to the accumulation of water in the ruts when a film of water develops between the vehicle tyre and road surface. The presence of a film of water results in loss of contact between the vehicle tyre and the road surface and consequently loss of steering control and an increase in the possibility of crash occurrence (14). The relation of rutting to safety is of major concern. However, no clear relationship between rut depth and crashes has been published (15). The only relevant study found to examine the relationship between rutting and crashes was conducted on the Princes Highway West in Victoria (16), which showed that crash risk related to rutting increased in the deepest rutting sites only. Sites with ruts of 20 mm and deeper had a 60% increase in crash risk. However, results of a study carried out in Tennessee (USA) to determine the relationship between highway pavement conditions and vehicle crashes indicated that the rut depth did not affect crash prediction models significantly except for night and weather-related crashes (8). This was due to unapparent rut path at night and under a layer of water. Moreover, the accumulated water in wheel paths results in the potential for hydroplaning and aquaplaning of the vehicles and subsequently the possibility of crash occurrence in wet weather.

**METHODOLOGY AND DATA COLLECTION**

The study reported herein is considered to be fully controlled in terms of road related factors as the same intersections were used before and after treatment, so the only variation is related to surface condition. The effect of the variation in traffic volumes between before and after surface treatment was also controlled by using crash rates instead of their numbers in the assessment. For all sites, line marking availability and condition at the relevant sites were checked before and after treatment and found to have experienced a minor change in condition so its effect is considered controlled as well.

**Site Selection**

A large sample of signalised intersections has been selected, for which a broad range of data of interest is available over a ten-year period, from 2003-2013. These intersections have been filtered using Latitude and Longitude coordinates in Google map to remove unsignalised intersections. These coordinates have been used for each section of 100 m along the roads to find the exact locations of the signalised intersections. Due to the variation in chainages between different years, it was necessary to find the accurate location of the selected sample of signalised intersections for each year individually. A total of 99 sites were identified following the staged filtering process summarised below.

- Only the intersections and/or their immediate 200 m approaches that were subject to surface treatment between 2004 and 2012 were included to ensure availability of condition data one year before and after treatment. This was confirmed with maintenance records of surface treatments and reductions in roughness and rut depth after treatment. Acceptable ranges for the latter associated with relevant treatment types were based on the findings reported in (17). The types of treatment include thin asphalt surfacing and chip seal with or without a geotextile underlay.
• Skid resistance data was only available for the period 2006 to 2011 so only intersections that were treated during 2007-2010 were included in the sample to ensure availability of all pavement condition data one year before and one year after treatment.
• Only intersections with available crash data over 3 to 5 years before and after treatment were included. According to New Zealand’s high risk intersection guide (18), for before and after study the minimum period for after study is 36 months.
• Where relevant, intersections that were identified to contain tram tracks (light rail) were excluded to control their effect on the different pavement condition parameters.

Crash Data

All crash data were obtained from CrashStats (19) which contains information on crashes that occurred in Victoria for the 13 year period (2000-2013) for each intersection as provided by the Victorian police. This database contains details of the location, road user involved, level of injury, severity of crashes, number of vehicles involved in the crash, type of vehicle(s), type of crash according to Definition for Classifying Accidents (DCA) codes, moisture condition of roadway (wet/dry) at the time of crash and speed zone limit. This data was filtered to select only those crashes that occurred within 10 m of the selected sites or their approaches (immediate 200 m) using crash number, crash ID (Node ID) and chainages where crashes occurred. All crash data has been converted the crash rate which has the unit of number of crashes per a traffic volume of 10 million vehicles.

Pavement Surface Condition Data

Pavement surface condition parameters relevant to this study include surface roughness, rutting and skid resistance. Pavement surface condition data are usually collected once every two years in Victoria. Data of skid resistance are collected for both wheel paths using SCRIM and reported for each separately and their average in the form of average Sideway Force Coefficient (SFC). These data are adjusted to correct for load, speed and temperature. No adjustment for seasonal variation is applied as the test program for specific sites is usually carried out at the same time each year to control its effect (20). Data documented by SCRIM is a positive integer equivalent to the SFC*100. For skid resistance a sample of intersections which were treated in 2007, 2008, 2009 and 2010 has been selected due to the availability of skid resistance data for one year before and one year after treatment.

Roughness and rutting data are collected in Victoria using the Multi Laser Profilometer (MLP) and reported in terms of lane (average of two wheel paths) International Roughness Index (IRI) in m/km and rut depth in mm for each 100 m segment. For the purpose of analysis, skid resistance, roughness and rutting data were averaged over the treated length covering the intersection and/or its approaches.
Traffic Volume Data

Traffic volume data used in the analysis is in terms of Annual Average Daily Traffic (AADT). This data is available for a number of years, but growth factors were used to estimate volume data when data of a certain year was missing. Traffic volume data for 3-5 years before and after treatment were determined and used for calculating crash rates. Crash rate over a specific period (3 or 5 years) was calculated as the ratio of total number of crashes over that period to the total number of vehicles entering the intersection over the same period, in 10 Million Vehicles Entering the intersection (10MVE) (21).

DATA ANALYSIS AND RESULTS

A descriptive analysis is performed to study the distribution of crash data according to several variables. They include crash type or DCA, severity and road surface condition (wet/dry). This is followed by an assessment of pavement surface condition effects on the safety performance of intersections before and after treatment. The assessment includes paired t-test for comparing crash rates before and after treatment and Negative Binomial (NB) regression to assess the contribution of each factor in crash occurrence (over dispersion). To provide a balanced analysis, an equal period of crash data for before and after treatment for each intersection has been used. To maximise the power of analysis, the longest available period for each intersection (3 or 5 years) has been used.

Assessment of before and after Treatment

A graphical presentation of the results of total crash rate for before and after treatment is shown in Figure 1. Departure from the line of equality indicates that the crash rates have changed after treatment to some extent. The position of points above and below the line illustrates that there is a difference in crash rates between before and after treatment. If there was no change, all points would be located on the line crossing the origin. Similar findings has been reported in (22).
FIGURE 1 Graphical presentation of crash rate for before and after treatment

Distribution of Crashes

The distribution of crash data according to crash type or DCA, severity and road surface condition is presented in Figure 2. Figure 2a shows a slight variation in some crash types between before and after treatment but the percentage distribution of crashes by type is relatively similar. Paired sample t-test showed that there is no significant difference between before and after treatment for fatal crashes. However, for serious injury crashes, a statistically significant reduction in crash rates was obtained. Distribution of all crashes by road surface moisture condition is shown in Figure 2c, where a considerable tendency of crashes to occur in wet condition is apparent, before and after treatment.
Effect of Skid Resistance

The influence of wet surface condition on the relationship between crash numbers and skid resistance in SFC, for before and after treatment is presented in Table 1. For both groups, the relationship fluctuates with respect to the different categories of skid resistance but generally smaller percentages of crashes are associated with the higher SFC categories. The results also indicate that wet weather crashes represent 25 to 36 percent of the total number of crashes and could be related to skidding problems.
TABLE 1 Crash Numbers vs. Moisture Condition and SFC Category

<table>
<thead>
<tr>
<th>Skid Resistance Category (SFC)</th>
<th>Crashes before Treatment</th>
<th>Crashes after Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Wet</td>
</tr>
<tr>
<td>0.35 ≥ SFC &lt; 0.4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>0.4 ≥ SFC &lt; 0.45</td>
<td>22</td>
<td>9</td>
</tr>
<tr>
<td>0.45 ≥ SFC &lt; 0.5</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>0.5 ≥ SFC &lt; 0.55</td>
<td>18</td>
<td>8</td>
</tr>
<tr>
<td>0.55 ≥ SFC &lt; 0.6</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>0.6 ≥ SFC &lt; 0.65</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>0.65 ≥ SFC &lt; 0.7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.7 ≥ SFC &lt; 0.75</td>
<td>9</td>
<td>3</td>
</tr>
</tbody>
</table>

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Effect of Traffic Volume, Roughness and Rutting

The relationship between before and after treatment for traffic volume, roughness and rutting is presented in Figure 3. Figure 3a reveals that there is no significant difference in the relationship between traffic volume and crash number for before and after treatment. Figure 3b presents the relationship between pavement roughness and crash rates for before and after treatment. The figure indicates that the trend is positive for before treatment and negative one for after. The latter implies that sections with higher roughness are associated with lower crash rates. The relationship between rutting and crash rates for before and after treatment is negative indicating a lower crash rate when deeper ruts are present. Relationships of crash rates with different roughness and rutting values for after treatment indicate a decrease in the number of crashes in the treated areas, confirming the advantage of the treatment. The relationships are weak as represented by the coefficients of determination of best fit linear lines. However, the purpose of this analysis is not to develop prediction models but to assess the overall trend and its direction i.e. positive or negative.

To provide a magnitude of scale to this study, the numbers of sites for different roughness and rutting categories have been presented in Table 2. The crash rates associated with different roughness and rutting categories have been plotted, as presented in Figure 4. From this figure, the following can be observed.
FIGURE 3 Relationship between before and after treatment for a) traffic volume, b) roughness and c) rutting
### Table 2 Number of Sites vs. Roughness and Rutting Categories

<table>
<thead>
<tr>
<th>Pavement Surface Condition</th>
<th>Before Treatment</th>
<th>After Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Category</td>
<td>No. of Sites</td>
</tr>
<tr>
<td>Roughness, (IRI) m/km</td>
<td>1 ≥ IRI &lt; 1.5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1.5 ≥ IRI &lt; 2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>2 ≥ IRI &lt; 2.5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>2.5 ≥ IRI &lt; 3</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>3 ≥ IRI &lt; 3.5</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>3.5 ≥ IRI &lt; 4</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>4 ≥ IRI &lt; 4.5</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>4.5 ≥ IRI &lt; 5</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>5 ≥ IRI &lt; 5.5</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>5.5 ≥ IRI &lt; 6</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>6 ≥ IRI &lt; 6.5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>6.5 ≥ IRI &lt; 7</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>7 ≥ IRI &lt; 7.5</td>
<td>1</td>
</tr>
<tr>
<td>Rutting, (Rut) mm</td>
<td>1 ≥ Rut &lt; 2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2 ≥ Rut &lt; 3</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>3 ≥ Rut &lt; 4</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>4 ≥ Rut &lt; 5</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>5 ≥ Rut &lt; 6</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>6 ≥ Rut &lt; 7</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>7 ≥ Rut &lt; 8</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>8 ≥ Rut &lt; 9</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>9 ≥ Rut &lt; 10</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>10 ≥ Rut &lt; 11</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>11 ≥ Rut &lt; 12</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>12 ≥ Rut &lt; 13</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>13 ≥ Rut &lt; 14</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>14 ≥ Rut &lt; 15</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>15 ≥ Rut &lt; 16</td>
<td>2</td>
</tr>
</tbody>
</table>

- unavailable

- For before treatment data, Figure 4a shows a fluctuating pattern of crash rate for different ranges of roughness with the highest crash rate occurring at an IRI of 2-2.5. By excluding roughness categories of crash rates related to only one site, an inverted U shape was found to be the best fit using a power function with R²=0.6 which indicates that crash rate increases between an IRI of 1 and 4.5 and decreases with higher categories. This finding shows that a reduction in the driving speed may be induced by the driver due to an increase in pavement roughness which results in a reduction in crash rate.

- For after treatment data, by excluding roughness categories of crash rates related to few sites and restricting the roughness data within categories 1-1.5 and 3-3.5 IRI, a linear function with a R²=0.71 was obtained.

- Figure 4b (before treatment and after treatment) illustrates fluctuating patterns of crash rates along the lower and higher ranges of rutting with the higher ranges of rutting being associated with lower crash rates. The reason for this is that shallow ruts are hardly visible to drivers which results in loss of contact between the vehicle tyre and the road surface and consequently loss of steering control and an increase in the possibility of
crash occurrence. However, for the deepest ruts drivers attempt to reduce their speed which leads to a reduction in crash occurrence. For the relationship between different rutting categories and crash rate for before treatment, the best fit function is linear with $R^2=0.28$. For after treatment data, by excluding rutting categories of crash rates related to only two sites, the best fit function is linear with $R^2=0.46$.

![Image](image1.png)

**FIGURE 4** Crash rate vs. a) roughness categories and b) rutting categories for before and after treatment

**Statistical Analysis**

A paired sample t-test was applied to the sample of signalised intersections using high severity crash data for the longest available period of crash data to determine whether there is a statistically significant mean difference between crash rates before and after treatment. The
average crash rate of 1.16 after treatment was lower than 1.65 before treatment. This resulted in a statistically significant reduction of 0.49 at 95% confidence level with a p value of 0.006. Also, the paired sample t-test was applied to the same sample of signalised intersections using fatality and serious injury crash data separately. Statistical results indicated that there is no significant difference for fatal crashes between before and after treatment. However, the average crash rate for serious injury crashes of 1.14 after treatment was lower than 1.59 before treatment. This resulted in a statistically significant reduction of 0.45 at 95% confidence level with a p value of 0.009.

For the data set used herein, the characteristic of response variable i.e. crash frequency data is that crash counts data and the variance of crash counts are greater than the mean (i.e. over dispersion) hence, the negative binomial is considered an appropriate model to overcome the over-dispersion problem in the data. In order to assess the contributions of different independent variables to crash occurrence, negative binomial regression was conducted for both before and after treatment data sets. For before treatment data, all variables including roughness, rutting, skid resistance and traffic volume were incorporated in the model as independent variables. In order to measure the effect of change in one factor related to other factors, the interaction effect was added to the model. The results showed the following:

- Not all predictors had a statistically significant contribution to explaining the variation in crash frequency.
- Intersections with higher traffic volumes are associated with higher crash frequency.
- Both traffic volume and the interaction between traffic volume and skid resistance contributed significantly with p values of 0.043 and 0.029 respectively at 95% confidence interval.
- By including speed limit into the model the interaction between traffic volume and skid resistance remained the only significant contributor with p value of 0.05.

A similar analysis was conducted for after treatment data and the results indicated that no independent variable had a significant contribution to crash occurrence. This indicates that the treatment has a considerable effect in improving skid resistance.

**CONCLUSIONS**

Before and after study was used to assess the effect of surface condition on safety performance of signalised intersections. Crash rates before treatment were determined and compared with crash rates after treatment to evaluate the effect of pavement condition on reducing crashes. Based upon the results of analysis presented, the following conclusions can be drawn:

1- A change in crash rates was observed from before treatment to after treatment and the reduction in the average crash rates for high severity crashes and serious injury crashes were statistically significant.
2- According to the distribution of crashes for before and after treatment, a slight variation in crash type (DCA code) has been observed.
3- Distribution of crashes by road surface moisture condition showed a considerable tendency of crashes to occur in wet conditions. Wet weather crashes generally represent 25-36% of total number of crashes.
No clear relationship was observed between crash number and different categories (levels) of skid resistance. High SFC categories were found to be associated with small percentages of crashes.

For before treatment data, there was no clear relationship between crash rates and different categories of roughness but it was observed that the highest crash rates occurred in the IRI range of 4-4.5. For after treatment, a fluctuating pattern of crash rate for different ranges of roughness with no particular pattern was observed.

For lower ranges of rutting data, no clear relationship was observed with crash rates but higher ranges of rutting were found to be associated with lower crash rates. This trend was true for both before and after treatment data sets.

Results of negative binominal regression analysis indicated that for before treatment, both traffic volume and the interaction between traffic volume and skid resistance were significant contributors to the crash occurrence. However, for after treatment no independent variable was significantly contributed to the crash occurrence. This indicated that the treatment had a considerable effect in improving skid resistance.

Intersections with higher traffic volumes were associated with higher crash frequency. This trend was more evident in the before treatment data set.

ACKNOWLEDGEMENT

The authors express their appreciation for the support of State Road Authority of Victoria in providing all data and relevant information for this study.

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