Agenda

1. Introduction
2. ‘At Fault’ Bus Accident Risk
3. Bus Routes With/ Without Priority
4. Total Traffic Effects?
5. Traffic Micro Simulation
6. Trams?
This paper presents an overview of a series of research programs exploring road safety and bus services...

- **Background:**
  - **Bus Road Safety:**
    - Project started as a study of bus safety
    - Found important effects of bus priority (signal and lane priority) on bus crashes so explored wider effects on all traffic
    - Found BIG impacts so the question was why?
    - Undertook a series of studies to identify why
  - **Tram/Streetcar**
    - Summarises early results for a similar new study of tram (streetcar) priority measures

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...all research is published in a series of research papers

### Bus

- **Factors Affecting ‘At Fault’ Bus-Involved Accidents (Including Bus Priority)**

- **Exploring Road Safety of Bus Routes With/Without Priority**

- **Before/After Effects of Bus Priority on Road Safety**

- **Road Safety, Bus Priority and Experimental Micro-Simulation**

### Tram

- **Before/After Effects of Tram Priority on Road Safety**

- **Tram Stops and Road Safety**

- **Hook Turns and Road Safety**
The research is part of a program funded by the Australian Research Council & partners

**Research Program**

**Goal**

to improve methodologies and guidance to enable the optimisation of design and implementation of public transport priority initiatives

**Team**

Graham Currie, Majid Sarvi, Research Fellow, 3 PhD Students

Dr David Logan – Monash University Accident Research Centre

Assoc. Prof Majid Sarvi – ITS (Monash)

Co-supervisors

Kelvin Goh – PhD Thesis Road Safety Impacts of Bus Priority Measures

Farhana Naznin – PhD Thesis Road Safety Impacts of Tram Priority Measures

Nick Hounsell

Nick Hounsell

Kelvin Goh

Farhana Naznin

...it is structured as follows

- ‘At Fault’ Bus Accident Risk
- Bus Routes With/Without Priority
- Total Traffic Effects?
- Traffic Micro Simulation
- Trams?
**Agenda**

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Analysis explored Bus drivers’ probability of being ‘at-fault’ in bus accidents including priority effect

- Mixed Logit Model of driver being at-fault:

\[ F_{i,n} = \beta_i x_{i,n} + \epsilon_n \]

where \( i = \text{at-fault} (=1) \) or not at-fault(=0) for driver \( n \)

\( X = \text{Vector of 16 driver, vehicle, roadway and environment factors} \)

Reference

Bus Priority/Divided Roads key accident reduction factors

- 2 vehicle and 5 roadway / environmental factors found significant

<table>
<thead>
<tr>
<th>Factor</th>
<th>Type</th>
<th>β</th>
<th>S.E.</th>
<th>t-Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus age - 25 years or more</td>
<td>Fixed</td>
<td>0.273</td>
<td>0.0969</td>
<td>2.82</td>
</tr>
<tr>
<td>Bus Length - 12m or less</td>
<td>Fixed</td>
<td>-0.241</td>
<td>0.0415</td>
<td>-5.81</td>
</tr>
<tr>
<td>Divided Road</td>
<td>Fixed</td>
<td>-0.427</td>
<td>0.0501</td>
<td>-8.53</td>
</tr>
<tr>
<td>Speed Limit - 50kph &amp; below</td>
<td>Fixed</td>
<td>0.313</td>
<td>0.0404</td>
<td>7.73</td>
</tr>
<tr>
<td>Traffic - Moderate/Heavy</td>
<td>Random</td>
<td>-0.206</td>
<td>0.0370</td>
<td>-5.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.400)</td>
<td>(0.0363)</td>
<td>(11.03)</td>
</tr>
<tr>
<td>Daylight</td>
<td>Random</td>
<td>-0.125</td>
<td>0.0449</td>
<td>-2.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.418)</td>
<td>(0.0297)</td>
<td>(14.05)</td>
</tr>
<tr>
<td>Bus Priority</td>
<td>Random</td>
<td>-0.446</td>
<td>0.216</td>
<td>-2.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.26)</td>
<td>(0.447)</td>
<td>(5.05)</td>
</tr>
</tbody>
</table>

Indicative that divided roads and those with bus priority would help bus drivers

Reference

Causal/risk factors measured

**Driver-related**
- Above 60 year old - possibly reflecting declining driving skills
- <2 years working experience - also found in previous study (Tseng, 2012)
- Female driver
- Previous at-fault record - presence of accident prone mentality

**Vehicle-related**
- Longer / older buses - not surprising given buses are likely to be less responsive and had been subjected to greater wear-and-tear

**Roadway / Environment**
- Undivided / 50kph or lesser roads - indicate space issues faced by bus drivers, especially near bus stops (Wahlberg, 2002)
  - Light traffic - perhaps drivers letting guard down
  - Night time - lesser visibility
  - Lack of bus priority - space issue as highlighted

For road / bus agencies, findings suggest benefits in assigning
- Longer / bus agencies, findings suggest benefits in assigning
- Longer / older buses to experienced drivers
- Routes with bus priority and mainly arterial roads to less experienced drivers
This study aimed to ‘predict’ bus accidents on routes with/without priority using 2 methods (MENB, NNM)

- **Approach:**
  - Empirical analysis of bus accident type and frequency analysis to gain a broad understanding of the safety implications of implementing bus priority measures at a bus route-section level
  - Two accident prediction models developed to identify key traffic, transit and route factors associated with accident frequency as well as for model comparison purposes
    - mixed-effects negative binomial regression approach (MENB)
    - neural network principles (NNM), as recent studies have pointed to excellent function approximation abilities of neural network models to predict collisions/accidents

- **Data**
  - Traffic Incident Management System Grenda Transit (Ventura) – 2009-2011; 1,099 incidents on 99 bus routes
MENB is a regression model predicting accidents using traffic, frequency, stop density and bus priority variables

- Method 1 - Mixed-Effects Negative Binomial (MENB) Modelling of Bus Accidents
  - $E(A_{ij})$ representing the predicted number of accidents along bus route segment $i$ at time $j$, the structure of the MENB model is given as:
  
  $$E(A_{ij}) = \exp(X_{ij}\beta + L_{ij}l_i + T_{ij}t_i + \epsilon_{ij})$$

  where
  - $X_{ij}$ = Matrix representing factor contrasts and covariates
  - $\beta$ = Vector of pooled coefficients (fixed effect)
  - $L_{ij}$ = Matrix to account for location-specific effect
  - $l_i$ = Vector of coefficients representing location-specific effects
  - $T_{ij}$ = Matrix to account for time-specific effect
  - $t_i$ = Vector of coefficients representing time-specific effects
  - $\epsilon_{ij}$ = Vector of residual errors

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NNM can explore complex data relationships without need for functional forms;

- back-propagation algorithm adopted BPNN
- BPNN model was developed in MATLAB
- Single neuron output layer (accident frequency)
- Range of hidden neurons adopted
- Model run 10 times to obtain RMSE for comparison with MENB model

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Table 1: Summary Statistics of Variables Used in MENB Model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accident Frequency (Collisions/year)</td>
<td>0</td>
<td>29</td>
<td>3.68</td>
<td>4.89</td>
</tr>
<tr>
<td>Year* (2009=1; 2010=2; 2011=3)</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>0.82</td>
</tr>
<tr>
<td>Location^ (Segment 1 =1 to Segment 99 = 99)</td>
<td>1</td>
<td>99</td>
<td>50</td>
<td>28.58</td>
</tr>
<tr>
<td>Length of bus route segment (km)</td>
<td>2.5</td>
<td>55.0</td>
<td>15.94</td>
<td>10.11</td>
</tr>
<tr>
<td>Average Annual Daily Traffic (AADT) of segment^</td>
<td>1,495</td>
<td>78,433</td>
<td>7,335</td>
<td>6,286</td>
</tr>
<tr>
<td>Number of bus services per week</td>
<td>6</td>
<td>314</td>
<td>111.43</td>
<td>87.63</td>
</tr>
<tr>
<td>Stop Density (Number of bus stops/km)</td>
<td>0.53</td>
<td>7.33</td>
<td>2.50</td>
<td>0.941</td>
</tr>
<tr>
<td>Presence of bus priority (With = 1, otherwise = 0)</td>
<td>0</td>
<td>1</td>
<td>0.15</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Total Observations, $n = 297$

Note: * Coded as string variable as required in R software
^ Defined based on bus service route and presence of bus priority
^ The weighted average method is applied to compute the AADT value for segments that comprise more than one road sections

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Figure 1: Topology of a Three-Layered Feed-Forward Neural Network
The raw data show significant reductions in incident frequency for routes with bus priority

- 70% reduction in accidents with buses hitting stationary objects
- 80% reduction in buses hitting stationary vehicles
- 80% reduction in collisions in-out of bus stops
- Cause hypothesis – Bus Priority facilitates safer bus movements on roads with traffic

The MENB model shows risk factors are AADT, Rte Length, Service Frequency, Stop Density and NO bus priority

- bus accident frequency at the route-section level increases with:
  - traffic volume (AADT),
  - route length and
  - service frequency
- that having more bus stops per route km increases accident risks (p=0.000), while
- the presence of bus priority reduces accident risks (p=0.002).
- the presence of bus priority is associated with a 54% reduction in bus accident occurrence, of all severity levels. *(This data includes all accident types including property – not only police recorded accidents)*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-6.640</td>
<td>0.000</td>
</tr>
<tr>
<td>Services per week</td>
<td>0.006</td>
<td>0.000</td>
</tr>
<tr>
<td>Ln(AADT)</td>
<td>0.431</td>
<td>0.001</td>
</tr>
<tr>
<td>Ln(Route Section Length)</td>
<td>0.773</td>
<td>0.000</td>
</tr>
<tr>
<td>Stop Density</td>
<td>0.389</td>
<td>0.000</td>
</tr>
<tr>
<td>Bus Priority – Yes</td>
<td>-0.766</td>
<td>0.002</td>
</tr>
<tr>
<td>Bus Priority – No</td>
<td>0 (Reference)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Random Effect:</th>
<th>Variance</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>0.357</td>
<td>0.598</td>
</tr>
<tr>
<td>Location</td>
<td>0.195</td>
<td>0.441</td>
</tr>
<tr>
<td>Dispersion parameter, ( \alpha )</td>
<td>0.242</td>
<td></td>
</tr>
<tr>
<td>95% CI for ( \alpha )</td>
<td>[0.169,0.429]</td>
<td></td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-607.205</td>
<td></td>
</tr>
<tr>
<td>AIC</td>
<td>1232.4</td>
<td></td>
</tr>
<tr>
<td>( R^2 )</td>
<td>0.807</td>
<td></td>
</tr>
</tbody>
</table>
**BPNN Model** can be used to predict accident rates for specific sites

- Best model had 1 hidden layer with 4 neurons – example outputs

![Figure 3: Effect of AADT and stop density on accident frequency (route-section 25)](image)

![Figure 4: Effect of AADT and route length on accident frequency (route-section 25)](image)

![Figure 5: Effect of stop density and service frequency on accident frequency (route-section 25)](image)

Both models show similar results; MENB had slightly lower error

- **Key Findings – Method**
  - MENB model and BPNN model generally similar results
  - MENB model has lower error (RMSE=2.59 vs 2.75)

- **Key Findings Bus Priority:**
  - The safety effect of bus priority is apparent for all datasets. T-test results revealed that the safety effect of bus priority effect was statistically significant (p<0.05) in all datasets for both models.
  - The BPNN model showed that bus priority has the effect of reducing route-section level accident frequency by 53.4%.
  - Results from the MENB model showed that this effect was 53.5% (which is equivalent when using the parameter estimate obtained from the NB model in the previous section)

**Table 1: Sensitivity Analysis for Bus Priority**

<table>
<thead>
<tr>
<th>Model</th>
<th>Route-section Dataset</th>
<th>Predicted Accident Frequency (per km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>With Bus Priority</td>
</tr>
<tr>
<td>MENB</td>
<td>Without bus priority</td>
<td>0.093</td>
</tr>
<tr>
<td>(RMSE=2.59)</td>
<td>(N=252)</td>
<td>(S.D.=0.090)</td>
</tr>
<tr>
<td></td>
<td>With bus priority</td>
<td>0.499</td>
</tr>
<tr>
<td></td>
<td>(N=45)</td>
<td>(S.D.=0.293)</td>
</tr>
<tr>
<td></td>
<td>All route-sections</td>
<td>0.167</td>
</tr>
<tr>
<td></td>
<td>(N=297)</td>
<td>(S.D.=0.226)</td>
</tr>
<tr>
<td>BPNN</td>
<td>Without bus priority</td>
<td>0.173</td>
</tr>
<tr>
<td>(RMSE=2.75)</td>
<td>(N=252)</td>
<td>(S.D.=0.216)</td>
</tr>
<tr>
<td></td>
<td>With bus priority</td>
<td>0.432</td>
</tr>
<tr>
<td></td>
<td>(N=45)</td>
<td>(S.D.=0.289)</td>
</tr>
<tr>
<td></td>
<td>All route-sections</td>
<td>0.213</td>
</tr>
<tr>
<td></td>
<td>(N=297)</td>
<td>(S.D.=0.247)</td>
</tr>
</tbody>
</table>
The focus of study is the new SmartBus network in Melbourne, Australia

- 8 routes
- 200 buses
- Low frequency; 15 min headway
- Long Routes; Round Trip Time = 238 mins
CrashStats Before/After Data explored to understand road safety impacts of BUS priority measures

- Extensive implementation of priority measures on routes 900 to 903

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Type of Measures</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit Signal Priority (TSP) - 31 locations</td>
<td>Actuated Transit Phase with or without Queue Jump Lane</td>
<td>“B” Signal activated when presence of bus is detected</td>
</tr>
<tr>
<td></td>
<td>Phase Insertion / Deletion / Red Truncation / Green extension</td>
<td>Adjustment of cycle / phase timing when bus is detected</td>
</tr>
<tr>
<td>Non-Transit Signal Priority (non-TSP) - 25 locations</td>
<td>Clearways</td>
<td>Restricted parking on kerbside lane to facilitate to bus flows</td>
</tr>
<tr>
<td></td>
<td>Carub Extension</td>
<td>Widening of carriageway to facilitate bus movements</td>
</tr>
<tr>
<td></td>
<td>Full-Time or Part-Time Bus Lane</td>
<td>Dedicated lane for bus use only</td>
</tr>
</tbody>
</table>

Reference


Results show accident reduction particularly in the important FSI group; why?

Change in Crash Data Before/After Priority

- All Accidents: 116 before, 95 after, change of 21 (-18%)
- Fatal and Serious Accidents: 42 before, 29 after, change of 13 (-31%)
- Fatal Accidents: 3 before, 0 after, change of 3 (-100%)

Reference

Accident Type analysis hints at likely bus priority effects

Key Findings:
- 66% drop in on & off-path accidents
- 28% drop in rear-end accidents
- 50% drop in side collisions
- 31% drop in FSI accidents (42 to 29)

Reference
Analytical impact is a 14% crash reduction; space based priority -18%; time based -11%

- Robust before-after evaluation (Empirical Bayes method) employed
- Final results show 14% reduction in accidents

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Types of Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time Based</td>
</tr>
<tr>
<td>Number of Locations</td>
<td>31</td>
</tr>
<tr>
<td>Total observed crash counts in the “after” period</td>
<td>94</td>
</tr>
<tr>
<td>Expected crash counts in the “after” period</td>
<td>105.38</td>
</tr>
<tr>
<td>OR’</td>
<td>0.892</td>
</tr>
<tr>
<td>OR</td>
<td>0.889</td>
</tr>
<tr>
<td>SE(OR)</td>
<td>0.11</td>
</tr>
<tr>
<td>Safety Effect, 0</td>
<td>11.1%</td>
</tr>
<tr>
<td>90% confidence level</td>
<td>(-7%,29%)</td>
</tr>
</tbody>
</table>

* Significant at 90% level

- Time based measures opposite to those by study in Toronto, Canada (tram) – Likely due to lower bus frequency / pedestrian volume in Melbourne

Reference
Traffic Micro Simulation (TMS) is now a common tool for road traffic engineering including bus (tram) priority

Monash has been developing TMS as an experimental tool to explore bus priority and safety using DRAC/CPI metrics

- Surrogate Safety Measures (SSM) in Traffic Micro-Simulation Modelling:
  - DRAC - deceleration rate to avoid the crash
  - CPI – crash potential index
  - Can be used to relate accident risk in traffic
- AIMSUN model adopted to test following configurations >>>>>
Not all risk behaviour is represented in TMS; hence only some safety effects can be tested.

<table>
<thead>
<tr>
<th>No.</th>
<th>Location</th>
<th>Hypothesis</th>
<th>Testable Using Micro-simulation/SSM?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Corridor</td>
<td>Reduced risk of run-off accidents with bus lane acting as roadside buffer</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improved visibility for drivers with buses segregated from main traffic stream</td>
<td>Unclear</td>
</tr>
<tr>
<td>3</td>
<td>Uncontrolled</td>
<td>Reduced risk of rear-end accidents for vehicles entering side streets as bus lane allows vehicles (bus and turning traffic) to break away/separate from mainstream traffic and slow down before turning</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Intersections</td>
<td>Reduced risk of side-swipe accidents for vehicles entering main street as bus lane allows vehicle to pick up speed before joining mainstream traffic</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>Controlled</td>
<td>Reduced risk of rear-end accidents as vehicles move into bus lane before turning at intersection</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Intersections</td>
<td>Improved intersection visibility for vehicles with buses segregated from main traffic stream</td>
<td>Unclear</td>
</tr>
<tr>
<td>7</td>
<td>Bus Stops</td>
<td>Reduced risk of vehicles hitting rear of slowing or stationary bus</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Reduced risk of side swipe accidents as a result of vehicle changing lane to overtake slowing or stationary bus</td>
<td>Yes</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>Reduced side-swipe accident risk for buses moving off</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Bus Priority Scheme Effect - Methodology

- Two-stage modelling approach

Stage 1 Calibration

- Observed travel time: inbound
- Modelling travel time: inbound
- Adjust parameter values

Stage 2 Validation

- Observed difference
- No

Stage 3 Model Development: Data Extraction

- Scenario development
- Extract from DRAC: CP/CP Rules

Stage 1
Focused on modelling observed traffic and driving behaviour

Stage 2
Focused on replicating observed conflicts

Stage 3
SSAM software used to extract conflict information from vehicle trajectory files generated by AIMSUN
...and testing of the 3 road schemes at intersections/bus stops for 5 levels of traffic flow

- Modelling Approach:
  - Modelled using AIMSUN TMS system
  - 3 lane road (70kph speed limit) and 3 bus routes modelled
  - Model conflict analysis at 3 locations:
    - Intersections
    - Bus Stops
    - Entire Corridor
  - 5 levels of traffic flow tested
  - Models run 10 times and average outcome used

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Bus Priority Scheme Effect - Results

**No Bus Priority**

- More conflicts with turning vehicles

**With Bus Priority**

- Reduced number of conflicts
  - More conflicts with bus slowing down
  - Reduced number of conflicts
Bus Priority Scheme Effect - Results

**Key Findings**
- Kruskal-Wallis H test showed traffic volume has effect on all schemes at corridor level.
- However, volume effect not significant in schemes 2 and 3 at intersections and bus stops.
- At intersections, conflicts found to be consistently lower in schemes 2 or 3 than scheme 1.
- Similar observations recorded at bus stop locations.
- At corridor level, conflicts were generally higher in scheme 2 and lower in 3 as compared to 1.

**Conflicts at intersections**

A - Bus priority schemes reduce rear-end / lane-change conflicts.
B - Points to importance of additional capacity and implies mix of safety effects not being modelled.

Bus priority schemes 2/3 have less conflicts at intersections...
...and at bus stops; scheme 3 has less conflicts than 2

Conflicts at Bus Stops

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Melbourne has the largest streetcar network in the world

Vital Statistics

- 250km of double track
  - 6 triple track sections increase capacity
- 28 Routes
  - Plus 9 other part-time routes
- 487 vehicles
- 23M in-service km p.a.
- 1785 Stops
- Serving 180M passengers p.a.
A recent project explored tram priority impacts on road safety

Simple Before/After results suggest a 16% decline in crashes; -30% in serious accidents

Table 1: Severity, Accident Type and Vehicle involved in accidents along Roadway Segment

<table>
<thead>
<tr>
<th>Period</th>
<th>Crash Severity</th>
<th>Accident type</th>
<th>Vehicle type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal</td>
<td>Serious</td>
<td>Others*</td>
</tr>
<tr>
<td>Before</td>
<td>2</td>
<td>27</td>
<td>59</td>
</tr>
<tr>
<td>After</td>
<td>0</td>
<td>19</td>
<td>54</td>
</tr>
<tr>
<td>Change</td>
<td>-2</td>
<td>-8</td>
<td>-5</td>
</tr>
<tr>
<td>% Change</td>
<td>-100</td>
<td>-30</td>
<td>-8</td>
</tr>
</tbody>
</table>

*Others: Light or no injury
** Others: All Accidents including striking animal or objects
*** MC: Motor Cycles including moped Vehicle and bicycle
**** HGV: Heavy Goods Vehicle, including semi-trailer, trucks, (tram), buses and coaches
By accident type; pedestrian, same and opposing direction accidents have reduced most

Crash Type Changes
- Pedestrian involved accidents fell by 63% (from 19 to 7).
- Collision in same direction fell by 65% notably rear end and side swipe accidents
- Opposing direction accidents reduced by 69% (right/opposing turn removal)
- 55% decrease in crossing intersection accidents (hook turns and turn bans)
- 57% decline in U-turn and parking manoeuvring accidents (U-turn and parking removal)

Empirical Bayes method suggests a -9.2% crash reduction effect; 12.4% for tram lane treatments

Table 1: Results of Before-After analysis using the EB method

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Type of treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Signal Treatment</td>
</tr>
<tr>
<td>Number of locations</td>
<td>18</td>
</tr>
<tr>
<td>Total observed crash counts in the “after” period</td>
<td>82</td>
</tr>
<tr>
<td>Total expected crash counts in the “after” period</td>
<td>92</td>
</tr>
<tr>
<td>Adjusted Odds Ratio (OR)</td>
<td>0.930</td>
</tr>
<tr>
<td>Standard Error of OR</td>
<td>0.0507</td>
</tr>
<tr>
<td>Safety Effectiveness</td>
<td>+7.0%</td>
</tr>
</tbody>
</table>
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