Benefits of Advanced Traffic Management Solutions: Before and After Crash Analysis for Deployment of a Variable Advisory Speed Limit System

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Outline

• Background and Objective
• Corridor Overview
• Literature Review
• Data Sources
• Naïve Before After Study
  • Methodology
• Bayesian Analysis
  • Methodology
• Results and Conclusions
• Future Recommendations
Background and Objective

• OR 217 Active Traffic Management Project
  • Variable Advisory Speed Limit System
  • Traveler Information System
  • Adaptive Ramp Metering
  • Queue Warning System

• Three Main Goals
  • Improve Safety
  • Reduce Congestion
  • Utilize Existing Assets
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Objective: Evaluate the effectiveness of the Variable Advisory Speed Limit System in reducing crashes
Corridor Location
Corridor Overview

- 7.52 mile highway connecting Beaverton and Tigard
- Serves as an important connector between US 26 at the northern terminus and I-5 at the southern terminus
- 55 mile per hour speed limit
- 11 sets of on and off ramps
- High commuter volumes
- Approximately 110,000 vehicles per day in 2013
Corridor Overview

- Experiences sudden congestion
- Highly variable travel times
- Crash rate above the typical for Oregon highways
Corridor Overview

- Oregon Department of Transportation decided to implement an Active Traffic Management system as geometric changes such as adding lanes and braiding ramps had an estimated cost of 1 billion dollars

$1 billion for 7.5 miles
Corridor Overview

- 28 overhead VSL signs
- 7 mainline Variable Message Signs (VMS)
- 6 arterial VMS
- 4 roadway weather sensors
- 5 radar traffic sensors
- 12 Bluetooth sensors
- 20 mainline dual loop stations
Congestion sensitive rear end crashes comprise the largest portion of the crashes and particularly the more severe crashes from 2011 to 2014.
Corridor Crash Trends

High percentage of rear end crashes are Fatal or Injury crashes from 2011 to 2014.
Literature Review

• Several Applications of Variable Speed Limit Systems
  • Weather Responsive
  • Congestion Responsive
  • Work Zones

• Manual or Automated Switching
  • Earliest relied on an officials “feel” for appropriate speed
  • Threshold Induced
  • Algorithm Controlled

• Regulatory or Advisory

• Removal of Installed Systems due to failure
  • I-270 in Missouri removed their system of 5 years in 2013
Literature Review

• Study Methodology
  • Naïve Before After Studies
  • Empirical Bayes Analysis
  • Hauer is the main figure in developing Before After Studies using both methodologies, particularly Empirical Bayes

• Crash Reduction
  • 2% and 13% reduction in crashes in Finland (Rama and Schirokoff)
  • 20-30% reduction in Germany (Robinson)
  • 10-15% in London (Robinson)
  • 18% reduction on Flemish VSL system (Pauw, Daniels, Franckx, Mayeres)
  • Debate about whether reduction is due to system or improved signage increasing awareness (Corthout, Tampere & Deknudt)
  • Wide variety of systems and uses likely responsible for this variation in results
Literature Review

• OR 217 Evaluations
  • “Evaluating the Effects of a Congestion and Weather Response Advisory Variable Speed Limit System in Portland, Oregon” By Matthew Downey
  • “Measurement and Assessment of Driver Compliance with Variable Speed Limits Systems: Comparison of the US and Germany” by Gary Riggins
  • “OR217: Active Traffic Management One Year On” by ODOT
Literature Review Key Findings

• VSL Systems
  • Systems vary for usage
  • Safety impacts are mixed and contested
  • Not all are successful as I-270 example shows

• Naïve Before After
  • Often used in studies due to ease of use and intuitiveness

• Empirical Bayes
  • Extremely powerful tool in safety analysis but data intensive
    and not always possible.

• OR 217
  • Well studied corridor in recent years with well known past
    issues
Data Sources

- Washington County 911 Call Data (WCCCA)
  - Dates, limited injury information, and approximate locations
- Transportation Operation Center Data (TOCS)
  - Incidents reported to ODOT with dates, locations, direction
- Transportation Data Section Data (TDS)
  - Full data including dates, times, locations, collision types, conditions, and weather
  - Self reported crashes with more than $1500 of damage
  - Estimated that only 50% are reported
Data Sources

Before 7/23/2014

After 7/23/2014

WCCCA  n=1842

TOCS  n=510

TDS  n=1118

Preliminary Data  n=432

7/13/2016
Data Sources - WCCCA

- Primary database for study
- Processing the given location descriptions can yield the approximate milepost and direction of travel
- Adding weather data from nearby Hillsboro Airport or Portal provides rough weather estimates for the day
- Limited by lack of information about time of day, crash type, or detailed locations
- Only incidents in which 911 is called are captured
- 2894 incidents in the data, 1842 before VSL activation

<table>
<thead>
<tr>
<th>Incident</th>
<th>Date</th>
<th>Crash Type</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>110660937</td>
<td>3/7/2011</td>
<td>TAN</td>
<td>SW BEAVERTON HILLS HW/HWY 217 NB</td>
</tr>
<tr>
<td>110680158</td>
<td>3/9/2011</td>
<td>TAU</td>
<td>NW SUNSET HW WB/HWY 217 NB</td>
</tr>
<tr>
<td>110680323</td>
<td>3/9/2011</td>
<td>TAI</td>
<td>HWY 217 NB/26 S OF</td>
</tr>
<tr>
<td>110690132</td>
<td>3/10/2011</td>
<td>TAU</td>
<td>HWY 217 SB/SW ALLEN BV</td>
</tr>
<tr>
<td>110700749</td>
<td>3/11/2011</td>
<td>TAU</td>
<td>HWY 217 NB/SW HALL BV</td>
</tr>
<tr>
<td>110700782</td>
<td>3/11/2011</td>
<td>TAN</td>
<td>SW BEAVERTON HILLS HW/HWY 217 SB</td>
</tr>
</tbody>
</table>
Traffic Accident – Injury (TAI), Traffic Accident – No Injury (TAN), and Traffic Accident – Unknown Injury (TAU) are the primary sources used for analysis.

Before – 36 months
Traffic Accident – Injury (TAI), Traffic Accident – No Injury (TAN), and Traffic Accident – Unknown Injury (TAU) are the primary sources used for analysis.

After – 21 months
Traffic Accident – Injury (TAI), Traffic Accident – No Injury (TAN), and Traffic Accident – Unknown Injury (TAU) are the primary sources used for analysis.
Data Sources - TOCS

- Data limited to crashes that ODOT is made aware of in real time
- May not include crashes that do not affect operations or occurring outside of peak hours
- Data collected on a wide variety of crashes but filtered to only crash data before being provided
- 829 total crashes in dataset with 510 from the before period
TOCS

- Similar crash trends to the WCCCA data
- Reduction around north terminus
- No large changes at VSL locations
Data Source - TDS

- Most complete database with crashes detailed enough to analyze system impacts to target collisions such as rear ends
- Newer data is incomplete, as it may not yet be reported and in the database, and does not include any Property Damage Only (PDO) collisions
- Limited fully available data for after scenario and possibly misleading partial after data
- 1301 crashes in the database with 1118 before VSL activation
  - New data provides an additional 149 crashes from 2015
Naïve Before After Analysis

- Relatively simple analysis method requiring data about crashes prior to the treatment and after
- Typically relies on three years of before and after data
- Simplest version is a simple comparison of raw numbers for before and after
- More complex analysis corrects for factors such as traffic and study periods
- Name due to the potentially misleading results
Methodology

- Predict the number of after crashes using the before crash information
- After counts are compared to the prediction to determine the reduction
- Traffic and the length of study period interfere with predictions and require correction factors
- These correction factors have large impacts and must be precise and accurate to develop acceptable results
- The date correction factor is a ratio of days in the before and after period for each data set
Traffic Correction Factor

• The traffic correction factor is a ratio of the average traffic before and after the treatment

• This assumes a linear relationship between the number of crashes and traffic volumes
  • Common assumption in literature
  • Likely to be an accurate assumption given crash patterns on OR 217

• Long before period adds challenges to getting accurate values and importance to finding accurate values
Official ODOT Traffic Data

Official OR 217 Traffic Volumes

Objective
• Corridor Overview
• Literature Review
• Data
• Naïve
• Bayesian
• Conclusions

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7/13/2016

29
Portal provides a repository of traffic data for the entire Portland area.
Portal Traffic Data

- Monthly traffic volumes were obtained from Portal
- Data includes periods with no detectors
- Periods also have errors with no data or extremely large volumes
- Data is sanitized by removing extraneous values
  - Typically removed values are removed from the mean by a factor of 2 or more
Traffic Volumes

- Traffic volumes showed an 8.12% percent decline
- Consistent for both Northbound and Southbound traffic
- These monthly volumes were used in the Naïve Before After Analysis for all data sources
Naïve Before After - WCCCA

- TAI
- TAN
- TAU
- Overall

Number of Crashes

Change in Crashes

Number of Before Crashes

Number of After Crashes

n=2894
Naïve Before After - WCCCA
WCCCA Southbound

Objective - Corridor Overview - Literature Review - Data - Naïve - Bayesian - Conclusions

7/13/2016
WCCCA By Weather

- Clear
- Rain
- Snow

Change in Crashes

Number of Crashes

n=2894

7/13/2016
TOCS

• 9.99% crash increase in the after period
• No crash severity information available to conduct analysis
• Limited amount of data restricts abilities to segregate the data for further analysis
TDS – No 2015

- Change in Crashes
- Number of Before Crashes
- Number of After Crashes

n=1301
TDS – No 2015

Change in Crashes

Number of Crashes

- 50 %
- 40 %
- 30 %
- 20 %
- 10 %
0 %
+ 10 %
+ 20 %
+ 30 %
+ 40 %
+ 50 %

DARK  DAWN  DAY  DLIT  UNK  DUSK

Number of Before Crashes

Number of After Crashes

n=1301
TDS – No 2015

Number of Crashes

Change in Crashes

- 30 %
- 20 %
- 10 %
+ 10 %
+ 20 %
+ 30 %
+ 40 %
+ 50 %
+ 60 %
+ 70 %
+ 80 %
+ 90 %
+ 100 %

Number of Before Crashes

Number of After Crashes

n=1301

7/13/2016
TDS 2015

- Number of Crashes
- Change in Crashes

Number of Before Crashes
Number of After Crashes

n=1450
TDS 2015

Number of Crashes

Change in Crashes

-80 %  -60 %  -40 %  -20 %  +0 %  +20 %  +40 %  +60 %  +80 %

FATAL  INJ A  INJ B  INJ C  FATAL + INJ A

Change in Crashes

Number of Before Crashes

Number of After Crashes

n=1450
Summary

<table>
<thead>
<tr>
<th></th>
<th>TDS - New Data</th>
<th>TDS - Rear End</th>
<th>TDS</th>
<th>TOCS</th>
<th>WCCCA - SB</th>
<th>WCCCA - NB</th>
<th>WCCCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change</td>
<td>6.04%</td>
<td>2.80%</td>
<td>3.13%</td>
<td>9.99%</td>
<td>4.43%</td>
<td>3.99%</td>
<td>4.21%</td>
</tr>
</tbody>
</table>

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Statistical Validity

• Hauer methodology provides guidance on if enough data is present to reliably detect effects of certain magnitudes.
• A longer after study period increases the statistical reliability significantly
• WCCCA has enough data to reliably detect changes of around 8%
• TDS has enough to reliably detect around 10% changes
• TOCS is borderline and cannot reliably detect 10% changes
Summary

• TOCS data may have been increased due to ITS infrastructure reporting more crashes

• TDS 2015 data likely flattering as more crashes will be added to the database gradually.

• Overall the results are consistent with an increase in crashes after the VSL system was implemented with an average 4.94% increase

• Limited data and the short after period limits the definitiveness
Empirical Bayes Analysis

- Currently the most accurate analysis method for highway safety
- A statistical inference method to determine information from data
- Requires predictions for peer group crashes and actual counts to be applicable
- Accounts for the “Regression to the Mean” error
- Provides better precision and is ideal for situations with less data
- Method dates back to the 1700s but was popularized in safety by Ezra Hauer
Empirical Bayes

The peer group values are determined from the Safety Performance Function (SPF) and correlated with the crash records for the location.
Regression to the Mean

Site Selected Based on Short Term Trend

Expected Average Crash Frequency

Regression to the Mean Reduction

Reduction due to Treatment

Perceived effectiveness
Empirical Bayes Methodology

- Divide OR 217 into small “sites” that can be analyzed individually
- The SPF for freeway segments is applied
- All appropriate CMFs applied on result
- Local Calibration Factor
- Summation develops the total crashes for the corridor
- Create expected crash values from before crash volumes
- Compare with actual crash volumes for reduction
Site Segmentation

- Following guidelines in Draft HSM Chapter 18 a new segment starts at
  - All locations with changing cross sections
  - All ramp gore areas
- 23 total segments from Milepost 0.06 to 6.90
Site Segmentation
Site Segmentation

COMPONENT PARTS

Speed-Change Lane
Type: ramp entrance
Seg. length = $L_{en}$

SCen

Speed-Change Lane
Type: ramp exit
Seg. length = $L_{ex}$

SCex

Freeway Segment
Effective segment length, $L^* = L_{as} - L_{en}/2 - L_{ex}/2$

(note: freeway segment length does not include the length of speed-change lanes, if these lanes are adjacent to the segment)

Fr1 .................................................. Fr2 .................................................. Fr3
Site Segmentation

- Reds shows a freeway segment
- Greens are the speed change lane
  - Dark green is entrance
  - Light green is exit
Segment SPF

- Separate SPF for each case
  - Multi Vehicle
    - Fatal and Injury
    - Property Damage Only
  - Single Vehicle
    - Fatal and Injury
    - Property Damage Only

- Based on roadway geometry and traffic

\[ N_{spf, f_s, n, mv, z} = L^* \times \exp(a + b \times \ln[c \times AADT_{f_s}]) \]
Speed Change Lane SPF

- Only done for Single Vehicle crashes
- Separate equations for ramp entrances and exits
  - Fatal and Injury
  - Property Damage Only
- Based on adjacent segment geometry and traffic
- All traffic volumes taken from ODOT ramp volume spreadsheets for 2011-2015

<table>
<thead>
<tr>
<th>Crash Severity (z)</th>
<th>Area Type</th>
<th>Number of Through Lanes (n)</th>
<th>SPF Coefficient</th>
<th>Inverse Dispersion Parameter $K_{sc, nEX, at, z}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal and injury (fi)</td>
<td>Rural</td>
<td>4, 6, 8</td>
<td>-2.679</td>
<td>0.903, 0.0005</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>4, 6, 8, 10</td>
<td>-2.679</td>
<td>0.903, 0.0005</td>
</tr>
<tr>
<td>Property damage only (pdo)</td>
<td>Rural</td>
<td>4, 6, 8</td>
<td>-1.798</td>
<td>0.932, 0.0005</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>4, 6, 8, 10</td>
<td>-1.798</td>
<td>0.932, 0.0005</td>
</tr>
</tbody>
</table>
Speed Change Lane SPF

- All traffic volume information was taken from ODOT ramp volume reports between 2011 and 2015
- Developed manually due to missing detectors
**Crash Modification Factors**

**Table 18-13. Freeway Crash Modification Factors and their Corresponding SPF**s

<table>
<thead>
<tr>
<th>Applicable SPF(s)</th>
<th>CMF Variable</th>
<th>CMF Description</th>
<th>CMF Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeway segments or speed-change lanes</td>
<td>CMF_1, w, x, y, z</td>
<td>Horizontal curve</td>
<td>Equation 18-24, Equation 18-40</td>
</tr>
<tr>
<td></td>
<td>CMF_2, w, x, y, f</td>
<td>Lane width</td>
<td>Equation 18-25, Equation 18-41</td>
</tr>
<tr>
<td></td>
<td>CMF_3, w, x, y, z</td>
<td>Inside shoulder width</td>
<td>Equation 18-26, Equation 18-42</td>
</tr>
<tr>
<td></td>
<td>CMF_4, w, x, y, z</td>
<td>Median width</td>
<td>Equation 18-27, Equation 18-43</td>
</tr>
<tr>
<td></td>
<td>CMF_5, w, x, y, z</td>
<td>Median barrier</td>
<td>Equation 18-28, Equation 18-44</td>
</tr>
<tr>
<td></td>
<td>CMF_6, w, x, y, z</td>
<td>High volume</td>
<td>Equation 18-29, Equation 18-45</td>
</tr>
<tr>
<td>Multiple-vehicle crashes on freeway segments</td>
<td>CMF_7, f, ac, mv, z</td>
<td>Lane change</td>
<td>Equation 18-30</td>
</tr>
<tr>
<td>Single-vehicle crashes on freeway segments</td>
<td>CMF_8, f, ac, z, v, z</td>
<td>Outside shoulder width</td>
<td>Equation 18-35</td>
</tr>
<tr>
<td></td>
<td>CMF_9, f, ac, z, f</td>
<td>Shoulder rumble strip</td>
<td>Equation 18-36</td>
</tr>
<tr>
<td></td>
<td>CMF_10, f, ac, z, f</td>
<td>Outside clearance</td>
<td>Equation 18-38</td>
</tr>
<tr>
<td></td>
<td>CMF_11, f, ac, z, f</td>
<td>Outside barrier</td>
<td>Equation 18-39</td>
</tr>
<tr>
<td>Ramp entrances</td>
<td>CMF_12, sc, nEN at, z</td>
<td>Ramp entrance</td>
<td>Equation 18-46</td>
</tr>
<tr>
<td>Ramp exits</td>
<td>CMF_13, sc, nEX at, z</td>
<td>Ramp exit</td>
<td>Equation 18-47</td>
</tr>
</tbody>
</table>
Crash Modification Factors

- Curve geometry provided from an ODOT horizontal alignment document
  - Spiral curves adjusted per the methodology
- ODOT Highway Inventory Report provides lane widths, shoulder widths, median widths, and barrier types
  - Google Maps and Earth used to verify Inventory report
- Rumble strips evident in painted side stripes
- Lane Change CMF accounts for the auxiliary lanes
Local Calibration

- Oregon has not yet published information on calibrating SPF to local conditions for freeways
- The draft methodology for Chapter 18 of the HSM was developing using Washington State Highways
- Calibration is then assumed to be insignificant
Expected Values

- Overdispersion parameters calculated as part of the methodology
  - Dependent on geometry and traffic volumes
- These are used to weight the predicted values and actual crashes
- Expected values determined for each of the before years
Expected Values

- The average ratio of before expected to predicted is determined and applied to after predictions.
Empirical Bayes - WCCCA
Empirical Bayes - TOCS

Fatal and Injury

- Expected
- Actual

Crashes

0 50 100 150 200 250 300 350

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Empirical Bayes Summary

- Three of the four cases showed an increase in crashes
- WCCC A Injury shows a 10.5% decrease
  - Could be due to limited injury reporting information
- WCCC A overall shows a 13.9% increase
- TOCS shows 23.8% increase
  - Increased reporting still a potential cause
- TDS shows 21.6% increase
  - Value will change with increased data
Results and Conclusions

- Crashes appear to be increased as a result of the VSL system
- All data sources verify this increase
- Multiple analysis methods, crude and advanced, show similar increases
- The increase in accidents appears to be around 5% using a Naïve Before After analysis and 20% with a Empirical Bayes analysis
Results and Conclusions

- WCCCA is a decent, up to date proxy for safety but requires some additional data analysis
  - Continued inclusion of GPS data will be extremely beneficial
  - Lack of timestamps limits use
  - Injury information hard to utilize
- TOCS data not well suited for this analysis by comparison
- TDS data provides the most useful information
Results and Conclusions

• Increase in crashes could be due to drivers overwhelmed with information and losing focus
• Already has 11 sets of closely spaced ramps with signage for each
Future Recommendations

- Study again in 2 to 3 years
- More time for more data to come in, particularly TDS
- Longer study period will make results more statistically valid
Future Recommendations

• More research on user perceptions of the system
  • “Surveying Driver Satisfaction With an Active Traffic Management System with Variable Advisory Speeds”
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Acknowledgements

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  - Dr. Robert Bertini for the project and guidance as thesis advisor
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  - For easy to understand safety analysis methods

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  - TESPA crew for the help and sanity
  - ITE and others for support

- Family
  - Parents for the encouragement and support

- Omni-Means
  - For understanding and allowing schedule flexibility
Questions?

Thank you for attending