Multi-Criteria Trucking Freeway Performance Measures for Congested Corridors

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Thesis Committee

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8-12-2010
Introduction

• **Delay and Congestion Impact Freight Industry**
  - Timely deliveries
  - Increase in emission
  - Increase in cost
  - Difficulty scheduling

• **Early focus on passenger vehicles**
  - Current measures may not meet needs of all users (e.g., loop sensors)
  - Better understanding of Freight reliability = Better planning/engineering
Outline

• Background/Context of Problem
• Description of Data Sources
• Methodology
• Case Study Results
  • Recurring Congestion
  • Non-Recurring Congestion
• Conclusions
Background

Performance Measures
- Tools to evaluate current/future needs
- Travel time, speed, delay, & travel time reliability

Sources of Data & Focus of Current Research
- Loop Sensors
- Electronic Truck Transponders (Weigh-in-Motion)
- GPS technologies
Unique Contributions of this Work

OBJECTIVES:

• Combining Multiple Data Sources
  • GPS data from commercial trucks
  • Loop sensor data (Oregon DOT)
  • Incident data (ODOT ATMS)

• Create unbiased FPM
  • Separating trucks experiencing congestion vs rest/refuel
  • Develop alternatives to current PM

• Develop Multiple Criteria for Evaluating Freight Performance
  • Travel Time, Delay & Reliability
  • Freight Vehicle Emissions
  • Freight Vehicle Costs

Portland State University
Description of Data Sources Available

• PORTAL (SEE: [http://portal.its.pdx.edu](http://portal.its.pdx.edu))
  • Loop Sensor Data from ODOT

• Incident Data
  • Type, Severity, Approximate location, Start/End time (duration)

• GPS Truck Data
  • TruckID number, Date, Time
  • Position (Latitude/Longitude)

• Data Challenges
  • No common gap time btw readings
  • Multiple trips on same day
  • Different truck types (travel behavior)
Description of Data Sources Available cont.

- **GPS Truck Types**
  - **Through**
  - **Partial Through**
  - **Partial Local**
  - **Local**

- Develop Filter to ID Through Trucks
- Best Representation of Corridor Congestion
- Use Through Trucks to develop FPM
Methodology to Identify Through Trucks
• Purpose of Filter: To Identify Through Trucks for analysis

• Two Step Process:
  • Filter Process 1: Matching GPS Readings to Identify Potential Through Trucks
  • Filter Process 2: Comparison to PORTAL Average Travel Times
  • Integrates available data sets and ensures no stops midway for rest/refuel

Filter Parameters

- \( m_s \) = Start Milepost
- \( m_e \) = End Milepost
- \( r \) = Buffer radius
- \( t_b \) = Threshold to clear buffer
- \( t_c \) = Threshold to clear corridor and buffer
Filter Process 1: Matching GPS Readings to Identify Potential Through Trucks

1. Obtain milepost measures using ArcGIS
2. Determine $m_s$ and $m_e$
3. Look at points falling in buffer ranges
4. Distinguish individual trips by each truck using time thresholds $t_c$ and $t_b$ and identify the “start” and “end” points of each trip
5. Match readings in “start” buffer to downstream reading in “end” buffer occurring within $t_c$

Methodology cont.

Corridor Length $= |m_e - m_s|$
**Filter Process 1:** Matching GPS Readings to Identify Potential Through Trucks

6. Find all intermediate readings for a truck ID falling between the trip “start” and “end” readings

7. Adjust the “start” and “end” reading timestamp and milepost to begin at $m_s$ and $m_e$ using speeds obtained from the next closest reading

8. Obtain the travel time and speed through the corridor, and identify trip direction using milepost data
Filter Process 2: Comparison to PORTAL Average Travel Times

1. Data sorted by the “start” reading timestamp into time bins of 15 minute intervals.

2. Deviation Index is calculated using the PORTAL:
   For a 15 minute time bin $t$,
   Then the Deviation Index $g_k$ is defined as
   \[ g_k = \frac{|a_t - T_k|}{\sigma_t} \]
   Where:
   $a_t =$ PORTAL average travel time at time bin $t$
   $\sigma_t =$ PORTAL day-to-day standard deviation of travel time
   $T_k =$ the corridor average travel time for truck trip $k$

3. Truck trip is too far from the expected average if:
   \[ g_k > m \ast \sigma_t \]
   Where:
   $m =$ a user defined parameter
Filter Process 2: Comparison to PORTAL Average Travel Time

Through Truck vs PORTAL Corridor Average Travel Time

*Results following filter process 1, showing Deviation Index.
Methodology cont.

Filter Process 2: Comparison to PORTAL Average Travel Time

Through Truck vs PORTAL Corridor Average Travel Time

*Results following filter process 2, showing Deviation Index
Recurring Congestion Analysis
Recurring Congestion

- I-5 NB
- Wilsonville, OR to Vancouver, WA
- 31.75 miles
- Jan-Dec, 2007 (weekdays)
Results: Recurring Congestion

Through Truck vs PORTAL Corridor Average Travel Time
*Results following filter process 2, showing Aggregated Data and Std Err

- Portal Jan to Dec 2007
- GPS Through Jan to Dec 2007
**Results: Recurring Congestion**

**Summary of Findings:**
- Loop Sensors tend to underestimate congestion in PM peak period
- Std Err indicates less reliability in PM peak period

**Through Truck vs PORTAL CV in Corridor Average Travel Time**
*Results following filter process 2, showing Aggregated Data, Smoothed*
Using Recurring Congestion Travel Time Results, We Can Estimate:

- Freight Vehicle Costs
- Freight Vehicle Emissions
Recurring Congestion Cost Results
Estimating Freight Vehicle Costs

• **Freight Value of Time (VOT)**
  - Different than passenger vehicles
  - Variations in VOT ($/hr)
# Estimating Freight Vehicle Costs

- **Freight Value of Time (VOT)**

- **Monetizing Using Freight VOT**
  - Texas Transportation Institute
  - Urban Mobility Report
  - Basic Formulation
  - Incorporating Travel Time Variability

## TTI, 2009

<table>
<thead>
<tr>
<th>Daily Freight Vehicle Cost</th>
<th>Daily Freight Vehicle-Hours of Delay</th>
<th>Daily Freight Vehicle Volume</th>
<th>Freight VOT ($/hr)</th>
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## Cohen, 2000

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<th>Daily Freight Vehicle Cost</th>
<th>Daily Freight Vehicle-Hours of Delay</th>
<th>Travel Time Variability</th>
<th>Daily Freight Vehicle Volume</th>
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<td>Eq2:</td>
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</tbody>
</table>
Estimating Freight Vehicle Costs

• Freight Value of Time (VOT)

• Monetizing Using Freight VOT

• Monetizing Using Operating Cost
  • Cost to operate truck for one hour (CPH)
  • Marginal operating costs impacted by roadway conditions
  • ATRI 2010 study derived CPH = $83.68/hr

Operating Costs

Driver Costs
• driver wages
• driver benefits
• driver bonuses

Vehicle Costs
• fuel and engine oil
• truck/trailer lease or purchase
• repair and maintenance
• fuel taxes
• Insurance
• tires
• licensing and permits
• tolls
Estimating Freight Vehicle Costs

- Freight Value of Time (VOT)
- Monetizing Using Freight VOT
- Monetizing Using Operating Cost
- Compare to Costs During Congestion to Costs During Free-Flow Conditions
  - 52.05 mph; conservative
  - Accepted industry average (ATRI 2010)

VS
Results: Percent Increase Above Free-Flow

Percent Increase in Cost of Freight Vehicle-Hours of Delay Per Mile Relative to 52.05 mph Free-Flow Travel Time

% Increase in Daily Cost of Delay Above Free-Flow Conditions

- CPH and VOT
  - Variability: 19%
- Variability: 22% (low end)
- Variability: 31% (high end)
## Results: Summary of Costs Per Mile

Ten cost scenarios to quantify $/mile above cost during Free-Flow conditions

- **Operating Cost Per Mile**
  - $1,909/mile

- **Range of VOT and Cost Formulations**
  - $576/mile—costs by operator type
  - $2,551/mile—regional VOT, congestion markup and variability

- **Recommendations for Estimating Costs**
  - VOT should represent region & impact of congestion
  - VOT by operator or service type not recommended
Recurring Congestion
Emissions Estimation
Estimating Freight Vehicle Emissions

• Emissions and Air Pollutants

**Mobile Source Air Toxics (MSAT)**
- Acrolein
- Benzene
- 1,3-butadiene
- Diesel particulate matter
- Formaldehyde
- Naphthalene
- Polycyclic organic matter

**Criteria Pollutants (CP)**
- Ozone (O3)
- Particulate matter (PM)
- Nitrogen oxides (NOx)
- Lead (Pb)
- Sulfur dioxide (SO2)
- Carbon monoxide (CO)

**Greenhouse Gases (GHG)**
- Carbon Dioxide (CO2)
- Nitrous Oxide (N2O)
Estimating Freight Vehicle Emissions

• Emissions and Air Pollutants

• Factors Contributing to Freight Vehicle Emissions
  • Vehicle Size & Weight
  • Roadway Grade
  • Speed & Acceleration

From Barth & Boriboonsomsin, 2009
Estimating Freight Vehicle Emissions

• Emissions and Air Pollutants

• Factors Contributing to Freight Vehicle Emissions

• Estimating Emissions
  • EPA’s MOVES 2010
  • GHG, MSAT, CP
  • Project Level Analysis
Results: Percent Increase Above Free-Flow

GHG

Carbon Dioxide (CO2)
Nitrous Oxide (N2O)

CP

Total PM 10; Total PM 2.5
Oxides of Nitrogen (NOx)
Sulfur Dioxide (SO2)

MSAT

1,3-Butadiene;
Acetaldehyde;
Acrolein;
Benzene

Freight Vehicle-Hours of Delay Per Mile

Relative to Free-Flow Travel Time
### Results: Summary of Emissions (g/mile)

#### Emission Rates Above Free-Flow Emissions

- **CO2**
  - 24,099 g/mile daily
  - 50% daily increase

- **NOx**
  - 138 g/mile daily
  - 65% daily increase

- **PM 10 & PM 2.5**
  - 3.78 g/mile daily
  - 13% daily increase
Non-Recurring Congestion Analysis
Case Study: Non-Recurring Congestion

Non-Recurring Congestion Scope:
- Similar Methodology,
- 5-mile segment near incident
  - Incident Area
- Downstream Incidents

Purpose of Study:
1. Comparison btw Through-Incident Trucks And Partial-Through/Local
   Incident Area A: I-5 NB near Going St.
2. Impact of Incident on Freight Vehicle Travel Time, Costs, and Emissions
   Incident Area B: I-5 NB near Corbett Ave.
Non-Recurring Congestion Analysis:
Comparison btw Through-Incident Trucks
And Partial-Through/Local
Results: Incident Area A, Through-Incident

Through-Incident Truck Average Travel Time Crossing Incident Area A

*Results following filter process 2

- Portal Jan-Dec 2007
- Portal Incident Day Dec 12th 2008
- Through-Incident Trucks Dec 12th 2008
Results: Incident Area A, Partial-Thru/Local

Summary of Findings:
- Downstream incidents have effect
- Smaller Std Err with truck data using Through-Incident only
- Supports that bias exists when partial/local movements included
- Few samples, difficult to look at reliability measures

Partial-Through/Local Truck Average Travel Time Crossing Incident Area A

*Results following filter process 2
Non-Recurring Congestion Analysis:
Impact of Incident on Freight Vehicle
Travel Time, Costs, and Emissions
Results: Incident Area B, Through-Incident

Through-Incident Truck Average Travel Time Crossing Incident Area B

*Results following filter process 2

Travel Time (min)

- Portal Jan-Dec 2007
- Portal Incident Day Jun 8th 2007
- Through-Incident Trucks Jun 8th 2007

Time of Day

00:00 02:00 04:00 06:00 08:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00

B-1, B-2
## Results: Incident Area B, Costs & Emissions

<table>
<thead>
<tr>
<th>Costs—Regional VOT and 2.5 Congestion Markup</th>
</tr>
</thead>
<tbody>
<tr>
<td>• $416 per mile (94% inc. above free-flow conditions)</td>
</tr>
<tr>
<td>• $366 per mile (74% inc. above recurring conditions)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emission Rates During Incident Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above Emissions During Free-Flow Conditions</td>
</tr>
<tr>
<td>• CO2</td>
</tr>
<tr>
<td>• 3110 g/mile</td>
</tr>
<tr>
<td>• 95% increase</td>
</tr>
<tr>
<td>• PM 10 &amp; PM 2.5</td>
</tr>
<tr>
<td>• 0.67 g/mile daily</td>
</tr>
<tr>
<td>• 93% daily increase</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>NOx</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 16.08 g/mile daily</td>
</tr>
<tr>
<td>• 128% increase</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>MSAT</th>
</tr>
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<tbody>
<tr>
<td>• 0.01 g/mile daily</td>
</tr>
<tr>
<td>• 70% daily increase</td>
</tr>
</tbody>
</table>
Summary of Findings
Conclusions

• Integrated GPS, loop sensor and incident data

• New methodology to identify local and through trucks
  • Remove bias of trucks resting/refueling
  • Through trucks best indicator of congestion
  • Indications that loop sensor data may underestimate congestion in PM peak
  • Non-recurring congestion analysis points to bias if partial-through/local trucks included in analysis

• Successful application of methodology in both recurring and non-recurring conditions, although less data for incident days
Conclusions Cont.

Freight performance measures derived can be used to quantify:

- **Freight Vehicle Costs Using Standard Methods**
  - Wide range of VOT—regional and congestion factor
  - Including variability is important, particularly for freight
  - VOT by operator/service type not recommended

- **Freight Vehicle Emissions Using EPA’s MOVES 2010 Model**
  - Quantify GHG, MSAT and CP emissions
  - Allows for consideration of environmental and health impacts
  - Results could be used in a dispersion model

- **Methodology and Case Studies provide guidance**

- **Useful to both public agencies and freight carriers**
Acknowledgements

• Dr. Figliozzi, Dr. Monsere and Dr. Haire

• Jeffrey Short from the American Transportation Research Institute

• Oregon Transportation, Research and Education Consortium (OTREC) and FHWA

• Shreemoyee Sarkar, Computer Science, PSU

Thank you all for attending!!
Questions??

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References


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