Predicting Travel Time Reliability: Methods and Implications for Practice
Today’s Agenda

- SHRP 2 background (slides 2–6)
  - L03 Overview (slides 7–19)
  - Exploratory Analyses (slides 20–32)
  - Before/After Studies (slides 33–39)
  - Cross-Sectional Statistical Modeling (slides 40–52)
  - Congestion by Source (slides 53–66)
  - Summary (slides 67–73)
  - Question and Answer
SHRP 2 Background

- Authorized in 2005 highway bill at $205 million over 4 years
- ~ $170 million spent over 7 years
  - Roughly $40 million targeted toward traffic congestion with largest emphases on improving safety and renewing highways
SHRP 2 Background (cont.)

- Memorandum of understanding
  - Federal Highway Administration
  - American Associates of State Highway & Transportation Officials
  - National Research Council of the National Academies

- Administered by TRB under cooperative agreement with FHWA
Providing Outstanding Customer Service for the 21st Century

- Safety ($51M)
- Safe Highways
- Great Customer Service
- Reliable Travel Time
- Rapid Renewal and Lasting Facilities
- Reliability ($20M)
- Capacity ($21M)
- Better Transport Decisions
- Renewal ($32M)
The Reliability Focus Area

- Theme 1. Data, Metrics, Analysis, and Decision Support
- Theme 2. Institutional Change, Human Behavior, and Resource Needs
- Theme 3. Incorporating Reliability in Planning, Programming, and Design
- Theme 4. Fostering Innovation to Improve Travel Time Reliability
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SHRP 2 PROJECT L03

Analytic Procedures for Determining the Impacts of Reliability Mitigation Strategies
The Team

• Cambridge Systematics
• Texas Transportation Institute
• University of Washington
• Dowling Associates
• Street Smarts
• Consultants: Herb Levinson and Hesham Rakha
What is Travel Time Reliability?

Definition: A consistency or dependability in travel times, as measured from day to day for the same trip or facility.

Travelers on familiar routes learn to “expect the unexpected”
  • Their experience will vary from day-to-day for the same trip.

Reliability “happens” over a long period of time
  • Need a history of travel times that capture all the things that make them variable.
Weekday Travel Times
5:00-6:00 P.M., on State Route 520 Eastbound, Seattle, WA

Travel Time (in Minutes)

0 5 10 15 20 25 30
Jan 3 Feb 2 Mar 4 Apr 3

2 Incidents with Rain
3 Incidents
1 Incident with Rain
4 Incidents
Rain
1 Incident

Martin Luther King Day
Presidents Day

Number of Incidents

2003
Reliability Has Costs!

• Variability in travel times means that extra time must be planned for

• In other words, travelers have to leave earlier – they build in a BUFFER to their trip planning, or suffer the consequences

• These extra costs have not been accounted for in traditional economic analyses of transportation improvements
Reliability Has Costs (cont.)

- Planned extra time at least as costly as regular travel time
  - Some studies place the Buffer’s costs at 1-6 times higher than average travel time

- Some trips will still exceed the Buffer – late penalties

Reliability (or the lack of it) just says that travel times are inconsistent/variable – it doesn’t tell you why!
A Model of Congestion

Traffic Control Devices

Daily/Seasonal Variation

Special Events

Physical Capacity

Demand Volume

Base Delay

Disruption-Related Delay

Total Congestion & Reliability

Roadway Disruptions

- Planned Emergencies
- Emergencies
- Planned
- Emergencies
- Special Events

- Daily/Seasonal Variation
- Special Events
- Special Events

- Traffic Control Devices
- Demand Volume
- Demand Volume
- Demand Volume

- Roadway Disruptions
- Roadway Disruptions
- Roadway Disruptions

- Work Zones
- Incidents
- Incidents

- Physical Capacity
- Physical Capacity
- Physical Capacity

- Lowers capacity and changes demand
- Lowers capacity and changes demand
- Lowers capacity and changes demand

- ...determine...
- ...determine...
- ...determine...

- ...can cause...
- ...can cause...
- ...can cause...

- Traffic Control Devices
- Roadway Disruptions
- Roadway Disruptions

- Source of Congestion

\( n \) = Source of Congestion
The L03 Challenge

• Team decided early on that an empirical approach should be undertaken
  – Other SHRP 2 Reliability and Capacity projects concerned with modeling reliability

• Reliability is defined by a long history – at least a year – of travel times (a distribution)
  – Implies that automated equipment is the only feasible method of data collection, but...
The L03 Challenge (cont.)

• Automated equipment not deployed everywhere
  – Usually deployed along with operational countermeasures (no “before” condition)

• So, how can enough empirical data be collected to study the effect on reliability?
  – Tap existing data sources as much as possible
  – Rely on a cross-sectional predictive model
Analysis Data Set

- Traffic Data
  - Volumes
  - Speeds
- Incident Data
- Weather Data
- Incident Management
- Geometric Characteristics
- Section Reliability Measures
- Section Traffic Characteristics
  - Demand
  - Traffic Statistics
- Agency Generated
- Traffic.com
- NWS Hourly Obs
  - Service Patrols
  - Policies
  - Capacity
  - Bottleneck
  - Ramp Meters

Analysis Data Set
The Analysis Approach: 4-Pronged

1. Exploratory Analysis
   Result: Test Assumptions and Metrics

2. Before/After Studies on Selected Study Sections
   Not planned in an experimental sense
   Result: reliability adjustment factors (% change)
The Analysis Approach: 4-Pronged (cont.)

3. Cross-Sectional Statistical Modeling

Macro-level Result:

\[ \text{Reliability} = f\{\text{volume, capacity, disruptions}\} \]

4. Congestion-by-Source

Micro-level Estimation Method for the “Congestion Pie”
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EXPLORATORY ANALYSES
Exploratory Analyses

1. Section length test: What is the effect of building study sections from detectors?

2. Data requirements for establishing reliability: how much data is enough?

3. Sensitivity of reliability measures to changes in highway performance

4. Trends in reliability
Exploratory Analyses (cont.)

5. Defining the peak hour and peak period
6. Estimating demand in oversaturated conditions on freeways
7. Reliability breakpoints on freeways
8. Sustainable service rates on freeways
Exploratory Analyses (cont.)

9. Travel time distributions on signalized arterials
10. Travel time distributions on rural freeways
11. “Vulnerability” to flow breakdown
12. Reliability of urban trips vs. links
Reliability Metrics

• Based on the history (distribution) of travel times for a section and time slice
  – **Section**: relatively homogenous stretch of highway (geometrics and traffic); bottleneck allowed at downstream end only
    • 4-6 miles for urban freeways and arterials
  – **Time Slice**: peak hour, peak period, mid-day, 24-hour weekdays, 24-hour weekend/holiday

• Use the Travel Time Index as the unit
Predicting Travel Time Reliability

Number of Trips

Travel Time (in Minutes)

On-Time at Mean + 10% = 85%

On-Time at Mean + 30% = 99%

Buffer Index = 0.19
Skew Statistic = 2.02
Planning Time Index = 1.39
Misery Index = 1.48
Reliability Metrics (cont.)

- **Statistical measures**
  - Buffer Index: \((95^{\text{th}} - \text{Mean})/\text{Mean}\)
  - Planning Time Index: \(95^{\text{th}}/\text{Ideal}\)
  - \(80^{\text{th}}\) Travel Time Index
  - Misery Index: \(97.5^{\text{th}}/\text{Ideal}\)
  - Skew Statistic: \((90^{\text{th}} - \text{Median})/(\text{Median} - 10^{\text{th}})\)

- **On-Time/failure measures: \% of trips that are:**
  - < threshold TTIs
  - < space mean speeds (50, 45, 30 mph)
How Much Data?

Error Rate vs. Months of Data

- TTI
- BI

Error Rate decreases as the number of months of data increases.
Signalized Arterial Reliability (ORL, 5 mi)

- Average Speed = 29 mph
- PTI = 1.588
- Buffer Index = 0.337
- Skew Statistic = 1.617
- Percent On-Time at 40 mph = 2.3%

P95 Travel Time = 30.5 min
Avg Travel Time = 22.8 min
Rural Freeway Trips (I-45, 60 mi)

- Average Speed = 65.4 mph
- PTI = 1.059
- Buffer Index = 0.033
- Skew Statistic = 1.121
- Percent On-Time at 40 mph = 65.8%

Avg Travel Time = 55.1 min
P95 Travel Time = 56.9 min
## Trends in Reliability: Atlanta

<table>
<thead>
<tr>
<th></th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Travel Time Index</strong></td>
<td>1.720</td>
<td>1.800</td>
<td>1.585</td>
</tr>
<tr>
<td><strong>Average Travel Time</strong></td>
<td>10.03</td>
<td>10.49</td>
<td>9.22</td>
</tr>
<tr>
<td><strong>95th Percentile Time</strong></td>
<td>14.27</td>
<td>15.15</td>
<td>13.60</td>
</tr>
<tr>
<td><strong>Buffer Index</strong></td>
<td>0.399</td>
<td>0.428</td>
<td>0.451</td>
</tr>
<tr>
<td><strong>80th Percentile Time</strong></td>
<td>11.87</td>
<td>12.40</td>
<td>10.99</td>
</tr>
<tr>
<td><strong>Skew Statistic</strong></td>
<td>1.186</td>
<td>1.196</td>
<td>1.308</td>
</tr>
<tr>
<td><strong>VMT Change</strong></td>
<td>+0.6%</td>
<td></td>
<td>-2.1%</td>
</tr>
</tbody>
</table>
Vulnerability: I-75 Atlanta, Station 750502, 2008

- Avg TTI
- 95%tile TTI
- Avg Volume

Time:
- 2:30 PM
- 2:45 PM
- 3:00 PM
- 3:15 PM
- 3:30 PM
- 3:45 PM
- 4:00 PM
- 4:15 PM
- 4:30 PM

Index:
- Avg Volume

Volume:
- 850
- 750
- 700
- 650
- 600
- 800
- 750
- 700
- 650

SHRP2
STRATEGIC HIGHWAY RESEARCH PROGRAM

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES
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BEFORE/AFTER STUDIES
Before/After Studies

• Urban freeway study sections revealed 16 before/after conditions
  – Ramp meters – 4
  – Freeway service patrol implementation – 2
  – Bottleneck improvement – 3
  – General capacity increases – 5
  – Aggressive incident clearance program – 2
  – HOT lane conversion – 1
SR-520 Ramp Metering
Peak Period: 6:00 – 9:00

<table>
<thead>
<tr>
<th></th>
<th>Seattle, WA</th>
<th>Before</th>
<th>After</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability Metrics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel Time Index</td>
<td></td>
<td>1.87</td>
<td>1.66</td>
<td></td>
</tr>
<tr>
<td>Buffer Index</td>
<td></td>
<td>0.32</td>
<td>0.31</td>
<td>-3.1%</td>
</tr>
<tr>
<td>Planning Time Index</td>
<td></td>
<td>2.46</td>
<td>2.17</td>
<td>-11.8%</td>
</tr>
</tbody>
</table>

*Other locations show similar reports (5-11% reduction in PTI)*
## Capacity Addition: PM Peak Period Comparison

- 405: add 1 GP lane to 2 existing GP + 1 HOV lanes

<table>
<thead>
<tr>
<th>Period</th>
<th>Travel Time Index</th>
<th>Buffer Index</th>
<th>Planning Time Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before (2007)</td>
<td>2.6</td>
<td>31%</td>
<td>3.4</td>
</tr>
<tr>
<td>After (2009)</td>
<td>1.5 (-42.3%)</td>
<td>44%</td>
<td>2.2 (-35.2%)</td>
</tr>
</tbody>
</table>
Capacity Addition

- **I-94**: add 1 GP lane to 2 existing lane

<table>
<thead>
<tr>
<th>Period</th>
<th>Travel Time Index</th>
<th>Buffer Index</th>
<th>Planning Time Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before (2001)</td>
<td>1.6</td>
<td>52%</td>
<td>2.4</td>
</tr>
<tr>
<td>After (2005)</td>
<td>1.1 (-31.2%)</td>
<td>28%</td>
<td>1.4 (-41.7%)</td>
</tr>
</tbody>
</table>

- **FSP expansion**
  - 15% reduction in unreliability (PTI)
  - 20% reduction in average travel time
Before/After: General Findings

• Capacity expansion projects will also improve reliability and operations improves the average/typical condition

• Implication: If reliability has additional costs to travelers, we’ve been missing a big part of the benefit stream for capacity projects
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CROSS-SECTIONAL STATISTICAL MODELING
Statistical Modeling

• Uses TTI distribution as the dependent variable

• “Data Poor” environment
  – No information available for disruptions
    • Not mechanistic
  – Link and section level prediction

• “Data Rich” environment
  – Uses causal factors to predict reliability
Statistical Modeling: Data Poor

- Results show that all reliability measures defined in the study can be predicted as a function of average Travel Time Index.

- Highway Types
  - Urban freeways
  - Rural freeways (long trips)
  - Signalized arterials
Link Level

95th Percentile TTI

Mean TTI
Section Level

![Graph showing the relationship between 95th Percentile and Mean TTI](image)
Statistical Modeling: Data Poor

• Allows reliability prediction from a wide variety of other methods/models that predict the average TTI
  – Except that our TTI includes the effect of all sources; models predict recurring-only

• \( \text{Overall Mean TTI} = 1.0274 \times \text{Recurring Mean TTI}^{1.2204} \)
Statistical Modeling: Data Rich

- Key TTI percentiles can be predicted as a function of:
  - “Critical” demand-to-capacity ratio
    - Most significant factor
    - Highest d/c ratio of individual segments on the section
  - Incident lane-hours lost
    (minimal work zones in data)
  - Hours where rainfall $\geq 0.05$
Statistical Modeling: Data Rich (cont.)

- $95^{th}$ Percentile TTI =

$$e^{\left(0.23233 \cdot dc_{crit} + 0.01222 \cdot ILHL + 0.01777 \cdot Rain05Hrs\right)}$$

- RMSEs $\sim 25\%$
Statistical Modeling: Data Rich (cont.)

- Incident lane-hours lost is the product of

  \[ \text{Number Incidents} \times \text{Lanes Blocked} \times \text{Duration} \]

- Number of incidents
  - Incident rate x VMT
    - Incident rate = Crash Rate/0.22

- Average incident duration
  - Statistical relationship has been elusive (link to TIM self-assessment scores is good, but number of points is limited)
  - Meta-analysis of past studies provides factors
Statistical Modeling: Data Rich (cont.)

• Lanes blocked per incident
  – 0.476 if shoulders and policy is to move incidents to shoulder
  – 0.580 if lane-blocking incidents are not moved to shoulder
  – 1.140 if useable shoulders are unavailable
Statistical Modeling: Data Rich (cont.)

- Average incident duration
  - Statistical relationship has been elusive (link to TIM self-assessment scores is good, but number of points is limited
  - Meta-analysis of past studies provides factors
  - Prime area for future research
Application Guidelines

• If your condition matches a B/A study closely, use the factors for it

• If not apply statistical models

• Meta-analysis of recent studies, which have not considered reliability, can be linked to Data Rich independent variables
  – E.g., incident duration, demand reduction
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CONGESTION BY SOURCE
Congestion by Source  
A Simple Analysis with Atlanta Data

- Identified days where incidents and precipitation occurred
  - Recurring only ........................................... 47%
  - Incident .................................................. 35%
  - Precipitation .......................................... 10%
  - Incident + Precipitation ............................ 8%

- No attempt to account for "what would have happened without an event"
Congestion by Source: Atlanta (cont.)

- There is still a lot of variability on recurring-only days
  - Planning Time Index = 1.47

- Volumes noticed to be lower on nonrecurring days
A More In-Depth Look: Seattle

• Multiple data sources for incidents
• 40 sections, ~3-4 miles each
• Careful assignment of multiple causes on individual days
## Congestion-by-Source

### Special Seattle Analysis
(Adjusted for “what would have happened”)

<table>
<thead>
<tr>
<th>Causes of Congestion</th>
<th>Unadjusted Percent of Delay</th>
<th>Adjusted Percent of Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incidents (crashes, breakdowns)</td>
<td>38.5%</td>
<td>28.5%</td>
</tr>
<tr>
<td>Bad Weather (Rain)</td>
<td>17.7%</td>
<td>13.1%</td>
</tr>
<tr>
<td>Construction</td>
<td>1.2%</td>
<td>1.0%</td>
</tr>
<tr>
<td>No Cause Indicated (mostly volume/recurring)</td>
<td>42.6%</td>
<td>57.4%</td>
</tr>
</tbody>
</table>
Wide Variation at the Corridor Level

Percent Delay Not Related to Disruptions

Lane-Hours Lost

0.00% 10.00% 20.00% 30.00% 40.00% 50.00% 60.00% 70.00% 80.00%
Probability of Being in Congestion
Rain Versus No Rain SR 520 Westbound
From Bellevue to Seattle
Probability of Being in Congestion
Rain Versus No Rain I-90 Westbound
From Issaquah to Bellevue
Increase in Mean Travel Times
With the Increase in Probability of Congestion Due to Rain
I-90 Westbound from Issaquah
Comparison of Mean Travel Times
With and Without the Influence of Incidents
I-5 Northbound Through the Seattle Central Business District
Congestion by Source Findings

- Volume is the primary factor ("starting point") in congestion and the effect of any given type of disruption
  - Congestion only forms when disruption is big enough to reduce capacity below demand

- On large (3+ lane per direction) roads, congestion is unlikely (<20%) to form at V / C ratios below 0.8 if no disruption event occurs

- On smaller (2 lane) freeways this value can be as low as 0.6
Congestion by Source Findings

- Disruptions in the leading shoulder of a peak have larger/longer effects than those in the peak or trailing shoulder.

- “Recovery” from congestion appears to be affected by background traffic volume more than by incident duration.
Congestion by Source Findings

• Effects vary significantly from corridor to corridor, depending on the nature of the traffic volumes and routine congestion patterns

• In general, corridors with low recurring delay (e.g., low v/c ratios) have the highest % of “No Cause Indicated”
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➢ Summary (slides 67–73)

• Question and Answer
Summary
What We Have and How It Can Be Used

• Large database that will continue to be used in other studies
  – Being used now on SHRP 2 Project C10: Partnership to Develop an Integrated, Advanced Travel Demand Model and a Fine-Grained, Time-Sensitive Network
  – FHWA Research (Active Transportation and Demand Management for the Highway Capacity Manual)
Summary
What We Have and How It Can Be Used

• Predictive relationships for reliability
  – Useful for other SHRP 2 projects
    • L04: Incorporating Reliability in Models
    • L05: Incorporating Reliability in Planning and Programming
    • L07: Geometric Design for Reliability
    • L08: Adding Reliability to the HCM
  – Can be used in current planning and corridor studies
Summary
What We Have and How It Can Be Used

• Foundational research on reliability and congestion
  – Will inform the Congestion Management Process and expected performance-based Reauthorization requirements
  – Measures and data processing methods
  – Predictive relationships for reliability
Major Findings
From the Research

• Reliability is really just another attribute of congestion, in addition to temporal and spatial aspects

• **ALL** types of highway improvements will improve reliability
  – Operations, capacity additions, and demand management all contribute to improving reliability
Major Findings (cont.)

- Volume (demand) – and its relationship to capacity – is a major determinant of reliability
  - Determines base congestion and how severe disruptions will be
  - Volume can be used to determine when / where incident response vehicles are deployed
Major Findings (cont.)

• Not accounting for reliability misses a substantial portion of the benefits of transportation improvements

• “We’ve been selling ourselves short”, in an economic sense, in communicating the benefits of highways

• Valuation of reliability is still being studied; Ken Small previously found:

\[
\text{cost of travel} = f\{\text{mean travel time} + \text{buffer}\}
\]
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➢ Question and Answer
Question and Answer Session

• Please type your questions into this box

• We will answer as many of your questions as time allows
Thank you for joining the webinar.

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