Travel Time Estimation for Traffic Management and Traveler Information

Robert L. Bertini
Department of Civil and Environmental Engineering
Nohad A. Toulan School of Urban Studies and Planning
Portland State University
Oregon Transportation Research and Education Consortium

Transportation Seminar No. 200 • April 4, 2008
Objectives

- Travel time visualizations
- Travel time fundamentals
- Previous research
- Framework for sensor spacing
- Analytical tool for sensor spacing
- Future research
- Seminar perspectives
What Can I Do With Travel Time?

- Travel time is fundamental
- Can be used to generate other things
- Travel time is multimodal
What Can I Do With Travel Time?

- Measure it
- Guess it
- Report it
- Predict it
- Forecast it
If I Get It Wrong?

- Annoy travelers
- Destroy confidence in system
- Increase congestion
- Worsen safety
- Damage air quality
- Increase fuel consumption
How Can I Affect Travel Time?

- Increase/decrease mean value
- Increase/decrease variability
- Affect comparison between modes
“Prediction is very difficult, especially about the future.”

—Niels Bohr
Portland Travel Times
London Underground

Time Travel from Elephant & Castle

Travel Time Estimation for Traffic Management and Traveler Information
2004 Tsunami
Runoff Travel Time

Channel Concentrated Travel Time

Travel Time Estimation for Traffic Management and Traveler Information
Fire Station Response Time

Current Fire Station
Response Time from 412 E. 4th Street

Travel Time Estimation for Traffic Management and Traveler Information
New York Commuter Rail

Travel Times on Commuter Rail

The map shows the travel times, in minutes, from Manhattan to stations in the region’s commuter rail network during the evening rush. Each line indicates time in an additional 15 minutes. Trains are shown below.

EXPRESS TRAINS

“Express” lines that appear to double back on themselves indicate when stations tired from Manhattan have shorter travel times because of express trains.

SPEEDS OF THE TRAINS

Color coding indicates how fast, on average, the trains travel to reach their destination.

- High-speed
- Medium-speed
- Low-speed

Travel times are based on trains departing from the New Jersey Transit System’s Central Terminal (also known as “New York Penn Station”). The Central Terminal distance from the New York Penn Station is 1,400 miles. The table compares the efficiency of different trains.

Comparing the systems

<table>
<thead>
<tr>
<th></th>
<th>N.J. Transit</th>
<th>L.I.R.R.</th>
<th>Metro-North</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Riders</td>
<td>74 million</td>
<td>82.5 million</td>
<td>70.9 million</td>
</tr>
<tr>
<td>Ahamage Profit</td>
<td>$260,000</td>
<td>$250,000</td>
<td>$265,000</td>
</tr>
<tr>
<td>Average Fare Per Mile</td>
<td>$3.7 cents</td>
<td>$2.8 cents</td>
<td>$3.2 cents</td>
</tr>
<tr>
<td>Average Fare Per Kilometer</td>
<td>$1.22</td>
<td>$1.43</td>
<td>$1.52</td>
</tr>
<tr>
<td>Ridership</td>
<td>45.2 percent</td>
<td>45.4 percent</td>
<td>45.8 percent</td>
</tr>
<tr>
<td>Stations</td>
<td>482</td>
<td>416</td>
<td>439</td>
</tr>
<tr>
<td>Average Fares</td>
<td>13 years</td>
<td>9 years</td>
<td>17 years</td>
</tr>
</tbody>
</table>

Source: I.R.T. N.J. Transit, MTA-North, National Transit Database

Statue of Liberty – New York Penn Station

*Percent of riders that cover operating costs 1. Percent of riders that

Portland State University

Travel Time Estimation for Traffic Management and Traveler Information
Train journey times from Cambridge
Travel time difference train vs. car from Cambridge
Fundamentals

Slope = Speed

Distance

Travel Time

Time
Fundamentals

Distance vs. Time

Free Flow Travel Time

Actual Travel Time

Actual - Free Flow = Delay
Travel Time Estimation for Traffic Management and Traveler Information

Midpoint Method

Influence Area 4 → Travel Time 4 (at t = 0)

Influence Area 3 → Travel Time 3 (at t = 0)

Influence Area 2 → Travel Time 2 (at t = 0)

Influence Area 1 → Travel Time 1

Link Travel Time (TT1 + TT2 + TT3 + TT4)
Fundamentals – Two Detectors

Distance vs. Time

Travel Time

Travel Time Estimation for Traffic Management and Traveler Information
Measurement Parameters

- **Fixed Locations**
  - Stop Watch Method
  - Detectors (any kind)
  - RF Toll Tags
  - RF “Sign Posts”
  - Video Image (license plate)
  - Volume Based

- **Fixed Times**
  - GPS + Wireless Communication
  - Cellular Phone
Measurement: Fixed Locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_1$</td>
<td></td>
</tr>
<tr>
<td>$x_2$</td>
<td></td>
</tr>
</tbody>
</table>
Measurement: Fixed Locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_1$</td>
<td>$t_1$</td>
</tr>
<tr>
<td>$x_2$</td>
<td></td>
</tr>
</tbody>
</table>
Measurement: Fixed Locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_1$</td>
<td>$t_1$</td>
</tr>
<tr>
<td>$x_2$</td>
<td>$t_2$</td>
</tr>
</tbody>
</table>
Measurement: Fixed Locations

Distance

<table>
<thead>
<tr>
<th>Location</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_1$</td>
<td>$t_1$</td>
</tr>
<tr>
<td>$x_2$</td>
<td>$t_2$</td>
</tr>
</tbody>
</table>

Travel Time Estimation for Traffic Management and Traveler Information
Measurement: Fixed Times

<table>
<thead>
<tr>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_1$</td>
<td>$x_1$</td>
</tr>
<tr>
<td>$t_2$</td>
<td></td>
</tr>
<tr>
<td>$t_3$</td>
<td></td>
</tr>
<tr>
<td>$t_4$</td>
<td></td>
</tr>
<tr>
<td>$t_5$</td>
<td></td>
</tr>
</tbody>
</table>

Travel Time Estimation for Traffic Management and Traveler Information
Measurement: Fixed Times

<table>
<thead>
<tr>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_1$</td>
<td>$x_1$</td>
</tr>
<tr>
<td>$t_2$</td>
<td>$x_2$</td>
</tr>
<tr>
<td>$t_3$</td>
<td></td>
</tr>
<tr>
<td>$t_4$</td>
<td></td>
</tr>
<tr>
<td>$t_5$</td>
<td></td>
</tr>
</tbody>
</table>

Travel Time Estimation for Traffic Management and Traveler Information
Measurement: Fixed Times

- **Distance**
  - $x_1$
  - $x_2$
  - $x_3$

- **Time**
  - $t_1$
  - $t_2$
  - $t_3$
  - $t_5$

<table>
<thead>
<tr>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_1$</td>
<td>$x_1$</td>
</tr>
<tr>
<td>$t_2$</td>
<td>$x_2$</td>
</tr>
<tr>
<td>$t_3$</td>
<td>$x_3$</td>
</tr>
<tr>
<td>$t_5$</td>
<td></td>
</tr>
</tbody>
</table>
### Measurement: Fixed Times

**Distance vs. Time**

<table>
<thead>
<tr>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_1$</td>
<td>$x_1$</td>
</tr>
<tr>
<td>$t_2$</td>
<td>$x_2$</td>
</tr>
<tr>
<td>$t_3$</td>
<td>$x_3$</td>
</tr>
<tr>
<td>$t_4$</td>
<td>$x_4$</td>
</tr>
<tr>
<td>$t_5$</td>
<td></td>
</tr>
</tbody>
</table>

**Time Series**

- $x_1$: $t_1$
- $x_2$: $t_2$
- $x_3$: $t_3$
- $x_4$: $t_4$

**Travel Time Estimation for Traffic Management and Traveler Information**
Measurement: Fixed Times

<table>
<thead>
<tr>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_1$</td>
<td>$x_1$</td>
</tr>
<tr>
<td>$t_2$</td>
<td>$x_2$</td>
</tr>
<tr>
<td>$t_3$</td>
<td>$x_3$</td>
</tr>
<tr>
<td>$t_4$</td>
<td>$x_4$</td>
</tr>
<tr>
<td>$t_5$</td>
<td>$x_5$</td>
</tr>
</tbody>
</table>
Use Counts (TTI Method)
Use Counts (TTI Method)
Similar Idea Using Granular Data

![Graph showing the relationship between flow (vph) and speed (mph). The graph includes a trend line that suggests a relationship between the two variables.](image)
WSDOT Travel Times

WSDOT - 95% Reliable Travel Times

Local Traffic Info

- Puget Sound Traffic Cameras
- Traffic Conditions
- Incidents
- Travel Times
- Local Construction
- Map Archive

Where are you starting from?

Bellevue

Where are you going?

Seattle via I-90

What time do you need to get there?

8:00 AM

Bellevue - Seattle via I-90

Your 95% Reliable Travel Time is 24 minutes. 95% of the time you would need to leave at 7:36 AM to arrive by 8:00 AM.
Data Collection Was Difficult

Data Collection
Greenshields, et al., 1947

Speedometer
Greenshields, et al., 1957
Travel Time Estimation for Traffic Management and Traveler Information

Previous Research: LAFSP

**AM PEAK (6:30 - 9:30) & PM PEAK (3:30 - 6:30)**
32 Weekdays (June 24 to August 9, 1996) • 192 Hours

**INCIDENTS**
Field Logs
1560 Incidents

**TACH VEHICLES**
5.7 Minute Headways
3619 Runs

**LOOP DETECTORS**
48 Stations - 170 Controllers
240 Loops

**ADDITIONAL DATA**
FSP Scantrons • CHP CAD • Tow Companies • Video • Caltrans District 7

Probe travel time: 07/11/96, AM (7 cars)
Previous: Highway 18

6 Cameras/3 Sites (1 per direction)
- US 101 north of Lincoln City
- OR-18 near Otis
- OR-18 near Grand Ronde
Previous Research: Frontier

Mean speed = 51 mph
Previous Research: ODOT VMS I

- 15 directional freeway links
- 87 probe runs
- 516 miles/12 drivers
- 15 hours of data collected
Previous Research: ODOT VMS I

![Graph showing travel time estimation methods]

- Coifman (u/s)
- Coifman (d/s)
- Midpoint
- Coifman - Midpoint
- Coifman - Distwt
- Midpoint - Average
Previous Research: ODOT VMS I
Travel Time Estimation for Traffic Management and Traveler Information

Previous Research: ODOT VMS I

- Coifman (u/s)
- Coifman (d/s)
- Midpoint
- Coifman - Midpoint
- Coifman - Distwt
ODOT Phase II: Tufte

- Data quality
- Congestion
- 300 ground truth runs on I-5 and OR 217
- Other algorithms
- Average error ~5-7%
- Need for more detection, but where?
Motivation

- Ongoing efforts to improve freeway travel time estimates
- Display travel time ranges for key corridors
- Desire to provide additional detection
- Need for “optimal” decision-making aid
Portland ATMS

- Freeway Surveillance
  - 502 inductive loop detectors
  - ~175 stations
    - Dual loop (act as single loop)
    - 1.2 mile average spacing
    - Upstream of on-ramps
  - 135 ramp meters
  - 98 CCTV

- ATIS
  - www.TripCheck.com
    - Real-time speed map
    - Static CCTV images
  - 18 dynamic message signs (DMS)
    - 3 display travel times
Freeway Detector Locations

Travel Time Estimation for Traffic Management and Traveler Information
Portland Speed/Travel Time Info

Travel Time Estimation for Traffic Management and Traveler Information
Bus/Arterial Speeds

Travel Time Estimation for Traffic Management and Traveler Information
Hypothetical $x$-$t$ Plane

- Extrapolated Travel Time
- Actual Travel Time
- Free Flow Travel Time
- Delay

$\ell = \text{Segment Length}$

$\ell = \text{Segment Length}$

$t_1 = \text{Time Interval}$

Free Flow Speed

Over-prediction
Freeway Corridor Example

Travel Time Estimation for Traffic Management and Traveler Information
Traffic Flow Relation and Dynamics

Assumptions:

- 1 mile segment
- \( s \approx 0.1-1.0 \) mile
- \( q_A = 2000 \) vph
- \( q_C = 1800 \) vph
- \( v_f = 60 \) mph
- \( v_c = 30 \) mph
- \( v_{CD} = -17.1 \) mph
- \( v_{AC} = -7.5 \) mph
Travel Time Estimation for Traffic Management and Traveler Information

Density (veh/mi)

Flow (veh/hr)

$q_A = 2000$
$q_C = 1800$
$v_f = 60$
$v_c = 30$
$v_{AC} = -7.5$
$v_{CD} = -17.1$
Travel Time Estimation for Traffic Management and Traveler Information

Real data
I-5 Macadam
2/8/07
Types of Transitions

Distance

Frontal stationary

Forward forming

Backward forming

Rear stationary

Backward recovery

Forward recovery

Time
Types of Transitions

- Frontal stationary
- Backward recovery
- Forward forming
- Backward forming
- Rear stationary
- Forward recovery
Estimation When Homogeneous

VHT Actual = VHT Estimated
Types of Transitions

- Frontal stationary
- Backward recovery
- Forward recovery
- Rear stationary
- Forward forming
- Backward forming

Travel Time Estimation for Traffic Management and Traveler Information
Types of Transitions

- Frontal stationary
- Backward recovery
- Forward forming
- Rear stationary
- Backward forming
- Forward recovery
Types of Transitions

- Frontal stationary
- Forward forming
- Backward forming
- Rear stationary
- Backward recovery
- Forward recovery
Traffic Flow Relation and Dynamics

Travel Time Estimation for Traffic Management and Traveler Information
Transition Uncongested → Congested

\[
\ell \quad s
\]

\[tt_f\] \hspace{1cm} \alpha = \text{Lag Time} \hspace{1cm} t_c \quad \text{Congestion Signal}

\[j_1\] \hspace{1cm} j_2\] \hspace{1cm} \[t_{tf}\] \hspace{1cm} \[u_{max}\]

\[z\] \hspace{1cm} \[\ell\]

\[\text{Shock}\]

\[v_f\] \hspace{1cm} \[v_{AC}\] \hspace{1cm} \[v_c\]

\[\text{Transition Uncongested} \rightarrow \text{Congested}\]
Transition Uncongested $\rightarrow$ Congested

- $x$: horizontal axis
- $j_1$, $j_2$, $j_3$: vertical axes
- $v_f$, $v_{AC}$: velocities
- $tt_f$: time
- $\alpha$: Lag Time
- $t_c$: Congestion Signal
- Shock

Travel Time Estimation for Traffic Management and Traveler Information
Transition Uncongested → Congested

\[ t_c \quad Congestion \ Signal \]

\[ \alpha = \text{Lag Time} \]

\[ t_{tf} \]

\[ v_{AC} \]

\[ v_f \]

\[ s \]

\[ x \]

\[ j_1 \]

\[ j_2 \]

\[ j_3 \]

\[ u_{max} \]

Shock
Transition Uncongested $\rightarrow$ Congested

\[ v_c \]

\[ u_{\text{max}} \]

\[ j_1 \]

\[ j_2 \]

\[ j_3 \]

\[ \ell \]

\[ s \]

\[ t_{\text{tf}} \]

\[ \alpha = \text{Lag Time} \]

\[ t_c \]

\[ z \]

\[ v_{\text{AC}} \]

\[ v_f \]

\[ x \]

\[ t \]
Transition Uncongested $\rightarrow$ Congested

$\alpha = \text{Lag Time}$

$t_c = \text{Congestion Signal}$

$\ell = s$

$tt_f$

$u_{\text{max}}$

$v_c$

Shock

$\text{UNDER}$

$\text{OVER}$

Travel Time Estimation for Traffic Management and Traveler Information
Transition Uncongested → Congested

\[ \alpha = \text{Lag Time} \]

\[ t_t \]

\[ z \]

\[ u_{\text{max}} \]

\[ t_c \]

\[ \ell \]

\[ s \]

\[ v_f \]

\[ v_{AC} \]

\[ v_c \]

\[ \text{Congestion Signal} \]

\[ \text{Shock} \]

Travel Time Estimation for Traffic Management and Traveler Information
Sensor Density Affects Lag Time

\[ l = 0.50 \]

\[ x = 0.25 \]

\[ t = 0.33 \]

\[ \ell = 0.25 \]

\[ s = 0.10 \]
Transition Uncongested → Congested

![Graph showing sensor spacing vs. VHT (Vehicular Headway Time)](image)

- **Predicted VHT**: A dashed line indicating the predicted VHT based on sensor spacing.
- **Actual VHT**: A solid line indicating the actual VHT measured.

*Travel Time Estimation for Traffic Management and Traveler Information*
Transition Uncongested → Congested

Error (Absolute Value)

Predicted VHT

Error (Penalty)

Error (Additive)

Actual VHT
Traffic Flow Relation and Dynamics
Transition Congested $\rightarrow$ Uncongested
Travel Time Estimation for Traffic Management and Traveler Information

Transition Congested $\rightarrow$ Uncongested

- $v_c$: Congested Speed
- $v_{CD}$: Congestion Disappearance Speed
- $tt_c$: Congestion Time
- $\alpha'$: Lag Time
- $tt_f$: Travel Time
- $t_r$: Recovery Signal
- Wave: Propagation of Congestion

Diagram showing the transition from congested to uncongested traffic conditions.
Transition Congested→Uncongested

\[ t' = \text{Lag Time} \]

\[ v_c \]

\[ v_f \]

\[ j_1 \]

\[ j_2 \]

\[ j_3 \]

\[ \ell \]

\[ s \]

\[ tt_c \]

\[ tt_f \]

\[ t_r \]

\[ t \]
Transition Congested → Uncongested
Travel Time Estimation for Traffic Management and Traveler Information

Transition Congested → Uncongested

Sensor Spacing (miles)

VHT

Predicted VHT

Actual VHT
Transition Congested → Uncongested

Error (Penalty)

Error (Absolute Value)

Error (Additive)

Predicted VHT

Actual VHT

VHT Error vs. Sensor Spacing (miles)
Underprediction Only

Travel Time Estimation for Traffic Management and Traveler Information

Sensor Spacing (miles)

Actual VHT

Predicted VHT

VHT
Underprediction Only

![Graph showing VHT Error vs Sensor Spacing (miles)]
Underprediction Only

![Graph showing VHT Error and Sensor Spacing relationship]

- **VHT Error**: 15% to 21%
- **Sensor Spacing (miles)**: 0.0 to 1.0
- **Actual VHT**
- **Predicted VHT**
- **Error**

*Travel Time Estimation for Traffic Management and Traveler Information*
Considering Both Transitions

Sensor Spacing (miles)

Predicted VHT

Actual VHT

VHT
Travel Time Estimation for Traffic Management and Traveler Information

Considering Both Transitions

![Graph showing VHT Error vs. Sensor Spacing (miles)]

- VHT Error
  - Error (Additive)
  - Error (Penalty)
  - Error (Absolute Value)

Sensor Spacing (miles):

- 0.0
- 0.2
- 0.4
- 0.6
- 0.8
- 1.0

VHT Error:

- 25%
- 20%
- 15%
- 10%
- 5%
- 0%
- -5%
- -10%
- -15%
Considering Both Transitions

Travel Time Estimation for Traffic Management and Traveler Information

-15%  -10%  -5%  0%  5%  10%  15%  20%  25%

Sensor Spacing (miles)

VHT Error

Error (Additive)

Error (Penalty)

Error (Absolute Value)

Predicted VHT

Actual VHT

VHT

0.0  0.2  0.4  0.6  0.8  1.0

Travel Time Estimation for Traffic Management and Traveler Information
Detector at End of Section

Travel Time Estimation for Traffic Management and Traveler Information
Detector at End of Section

\[ t_{tf} = \alpha = \text{Lag Time} \]

\[ t_c = \text{Congestion Signal} \]
## Effects of Detector at End

### Regime AC

**Underprediction**

<table>
<thead>
<tr>
<th>Detector Location</th>
<th>$U_{\text{max}}$ (Min)</th>
<th>Lag Time (Min)</th>
<th>VHT/Mile Pred</th>
<th>VHT/Mile Act</th>
<th>Under % Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midpoint</td>
<td>0.56</td>
<td>4.00</td>
<td>2.78</td>
<td>3.55</td>
<td>22%</td>
</tr>
<tr>
<td>Downstream</td>
<td>0.11</td>
<td>0.00</td>
<td>0.56</td>
<td>0.59</td>
<td>5%</td>
</tr>
</tbody>
</table>

**Overprediction**

<table>
<thead>
<tr>
<th>Detector Location</th>
<th>$U_{\text{max}}$ (Min)</th>
<th>Lag Time (Min)</th>
<th>VHT/Mile Pred</th>
<th>VHT/Mile Act</th>
<th>Under % Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midpoint</td>
<td>0.56</td>
<td>4.00</td>
<td>4.44</td>
<td>3.95</td>
<td>-13%</td>
</tr>
<tr>
<td>Downstream</td>
<td>0.11</td>
<td>0.00</td>
<td>8.89</td>
<td>6.91</td>
<td>-29%</td>
</tr>
</tbody>
</table>
The Future

- Better estimates and forecasts
- Fusion of fixed and mobile sources
- Ubiquity of integrated information
  - In-vehicle
  - In-device
  - Multimodal routing/decision-making
  - Customizable
- Better management
Travel Time Estimation for Traffic Management and Traveler Information

Seminar Perspectives

- Inspired by Berkeley’s *Transportation Science Seminar*, originated by G.F. Newell, 1965
- First seminar October 5, 2000, *Benefits of Archived ITS Data: Measuring Capacity at a Freeway Bottleneck*
- 200 seminars completed
- Began streaming video October 2002: 165 available for download and streaming
- Began podcasts (mp3) in October 2007: 30 podcasts now available
- Venue for student/faculty interaction
- Strong involvement of transportation community
Travel Time Estimation for Traffic Management and Traveler Information
Seminar Perspectives

- Organized by graduate students?
- More social interaction before/after?
- More point/counterpoint?
- We’re open to other ideas!
- First air transportation seminar on May 9
- Other topics we haven’t covered?
Acknowledgements

- Travel time project teams, past and present
- Kristin Tufte, Sirisha Kothuri, David Lovell, Ben Zielke, Rafael Fernandez, Ed Anderson Sutti Tantiyanugulchhai, Roger Lindgren, Monica Leal
- Galen McGill, Jack Marchant, Dennis Mitchell, Oregon Department of Transportation
- Portland State University Distance Learning Center for making the streaming easy
- My colleagues Jennifer Dill, Chris Monsere and John Gliebe
- Seminar enthusiasts and participants
- Ryan Gratzer
TRANSPORTATION SEMINAR
CONGRATULATIONS
ON YOUR
200TH SEMINAR!