Creating transportation system intelligence using PeMS

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Summary

- Conclusion
- System overview
- Routine reports: Congestion monitoring, LOS
- Finding bottlenecks
- Max flow occurs at 60 mph
- Potential gains from ramp-metering
- Inefficiency of freeway operations
- Mobility measures: Predicting travel times
- Appendices
Conclusion

- The integration of IT at all levels of the transportation system greatly enhance freeway systems productivity

- Examples from Los Angeles illustrate opportunities to improve system management and assist travelers

- Integration of IT requires reengineering the operations, planning, and investment procedures constituting today’s transportation system
What is PeMS (Performance Measurement System)?

- PeMS collects and stores Caltrans loop detector data from traffic management centers (TMCs) throughout the state.

- PeMS is accessed via a standard internet browser and contains a series of built-in analytical capabilities to support a variety of uses.

- PeMS supports freeway operations, planning, travelers, and researchers.
PeMS collects and stores data captured by loop detectors in the State’s freeways in a central database. PeMS also obtains and stores CHP-published incident data.

The central database is currently located on the UC Berkeley campus, but it can be accessed from anywhere via the Internet.

Data are sent from the TMCs to UC Berkeley over the Caltrans wide area network (WAN).

PeMS users have different levels of access to the data, depending on needs.
Software architecture

- Bottom layer is database administration: disk management, crash recovery, table configuration

- Middle layer comprises software that works in real time. It
  - Aggregates 30-second flow and occupancy values into lane-by-lane, 5-minute values;
  - Calculates the $g$-factor for each loop at each time, and then the speed for each lane;
  - Aggregates lane-by-lane values of flow, occupancy, and speed across all lanes at each detector station. At this point, PeMS has flow, occupancy, and speed for each 5-minute interval for each detector station;
  - Computes basic performance measures such as congestion delay, vehicle-miles-traveled, vehicle-hours-traveled, and travel times

- Top layer comprises many built-in applications.
Status of PeMS

- PeMS is a functioning Internet application
- Real-time data from District 3, 4, 7, 8, 11 (pending bugs), 12 are sent to and stored in PeMS
- The system will be deployed in July 2002
Routine reports (congestion)

- Many monthly and annual reports and programs can be improved with PeMS
- The HICOMP report presents location, magnitude, and duration of congestion for California freeways
- Information used to identify problem areas and establish priorities for operational and air quality improvement projects
- Data for the report are obtained from “floating” cars
- PeMS chart of min, max, avg congestion shows HICOMP report is unreliable
LOS determination

- LoS (Level of Service) is used in planning, air quality, and other studies.

- Table gives HCM 2000 relation between LoS and density (passenger cars/mile/lane).

- PeMS data used to calculate density.

<table>
<thead>
<tr>
<th>LOS</th>
<th>Density (pc/mi/ln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0-11</td>
</tr>
<tr>
<td>B</td>
<td>&gt;11-18</td>
</tr>
<tr>
<td>C</td>
<td>&gt;18-26</td>
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<tr>
<td>D</td>
<td>&gt;26-35</td>
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<tr>
<td>E</td>
<td>&gt;35-45</td>
</tr>
<tr>
<td>F</td>
<td>&gt;45</td>
</tr>
</tbody>
</table>
Density contour plot

Contour plot for 10-E, Density (v/l), 2/4/2001
(traffic flows from bottom to top, or increasing postmile)
Using days (mon,tue,wed,thu,fri)

Hour:Min

Postmile (mi)
LoS for LA (am peak)
LoS for LA (midday)
LoS D7 vs D8 (all hours)
Identifying bottlenecks

- Select freeway section, time, and variable (e.g., speed)

- Plot shows average speed on I-10W from pm20 to 50 at 7.30 am on September 14, 2000.

- Two potential bottlenecks at pm 23 and 32 where speed drops sharply.
Identifying bottlenecks (contd)

- Bottleneck confirmed from PeMS contour map application
- Repeat confirmation from other days
- Engineer can focus on causes (geometry, interchanges, demand) and measures to alleviate bottleneck
**Maximum flow occurs at 60 mph**

- Highway Capacity Manual gives speed-flow curve with max flow between 35-50 mph

- Max flow at 3,363 detectors on Sept 1, 2000, between midnight and noon shows max flow at 60 mph

- So congestion should be defined as extra delay driving below 60 mph
Maximum flow occurs at 60 mph (contd)

- Ramp-metering will be effective only if it maintains free flow
- Speed below 50 mph cannot be sustained
Potential gains from ramp metering

- Select freeway section I-10W, pm 22 to 38, Jan 11, 2001, 4.00 am to noon

- Hypothesis: if flow is maintained below max observed flow (less 3%), then speed will be 60 mph

- Ramp-metering imposes this policy

- Application calculates total delay, and delay at ramps

- Calculates ramp queues

- For LA, annual congestion delay estimated at 75 million vehicle-hours of which 50 million is eliminated by this policy
Inefficiency of traffic operations

- Previous figure shows at 7.00 am flow is 1300 v/h/ln and speed is 15 mph. So efficiency is

  \[ \eta = \frac{Flow \times Speed}{MaxFlow \times SpeedAtMaxFlow(60)} = 13\% \]

- Formula based on queuing system. Customer is vehicle, service is transport across segment, service time is

  \[ \frac{SegmentLength}{Speed} \]

- \( Flow \) customers served in parallel, so throughput is

- Max throughput is

  \[ \frac{Speed}{SegmentLength} \times Flow \]

- Efficiency is throughput/Max throughput

  \[ \frac{Flow \times SpeedAtMaxFlow(60)}{MaxFlow \times Seg\text{mentLength}} \times MaxFlow \]
Inefficiency of traffic operations (contd)

- Estimate efficiency of all 291 segments of I-10W at time of worst congestion on Oct 1, 2000, midnight to noon

- 78 segments have efficiency under 40%, 65 between 40 and 80%, 46 have efficiency larger than 100 (speed at max flow larger than 60 mph)

- $1 trillion dollar freeway system has very poor efficiency at time of greatest demand
Travel time variation

- Travel times for 20 days in October, 2000, on I-10E, between pm 1.3 and 48.5, starting every 5-min, between 5 am and 8 pm

- Unconditional distribution shows large variation

- 90% confidence interval for trip starting at 5 pm is between 55 and 110 min

- Travel time distribution, conditioned on current and past values, shows much smaller variation

- Permits prediction of travel time
Travel time prediction

![Regression Method](image)
Travel time prediction algorithm

- Given $V(d, x, t)$, velocity at location $x$ on day $d$ at time $t$
- Estimate $TT_e(a, b, t+s)$, travel time on day $e$ from $a$ to $b$ starting at $t+s$
- $M(a, b, t+s) =$ historical average of $TT_d(a, b, t+s)$
- $TT^*(a, b, t) =$ travel time with frozen velocity field $V(e, l, t)$
- $TTE_e(a, b, t+s) = \alpha(t, s)\ TT^*(a, b, t+s) + \beta(t, s)\ M(a, b, t+s)$
- Obtain $\alpha(t, s), \beta(t, s)$ by least-squares regression
Traveler information

- Speed maps, now common on the Internet and via cable TV, are available at PeMS website.
- The map also shows incidents. Clicking on an incident icon gives a description.
Traveler information

- PeMS provides travelers in LA travel time estimates and predictions from designated origin to destination for fastest route and 15 other routes
  - Exhibit shows an example
  - Fastest routes will also be provided for HOV vehicles
Traveler information scenario

Are I going to be late?
Sensor diagnostics

PeMS’ sensor diagnostics allow user to verify when sensors are not working or reporting data inconsistently

- Users can identify the total number of 30-second intervals of data received or the percent of the total day reporting
- Analysis can be done for any time period (i.e., hour, day, week, month, year) and any freeway segment, as illustrated here

PeMS is developing methods to monitor the data quality based on reasonableness of reported volumes, speeds, occupancies and agreement with neighboring values
Conclusions

- Think of freeway system as an agency that produces “transport services”
- Output is VMT
- Fixed input is “capital depreciation” and workforce that maintains system
- Variable input is travel time, measured as VHT
- So $Q = \frac{VMT}{VHT}$, measures productivity
- Presentation shows numerous examples to dramatically increase $Q$
Appendix 1: How to Access PeMS

- Go to the following URL:
  
  http://transacct.eecs.Berkeley.edu

- You need a username and password

- You can get these at the PeMS web site
  - Select “Login” and then “Apply for an Account”
  - Fill out the online form and select “Apply”
Web Site Layout

1) Introduction
2) Log-In
3) Select District
4) Select Analysis
Web Site Layout (continued)

- Select a District - This menu allows you to choose which district to examine. The current choices are District 7, 8, 3 (real-time data collection) or 12 (historical data).

- Select a Freeway - This menu allows you to choose the highway and direction you would like to examine. Otherwise, you can input the ID number of a specific loop.

- Plots - This menu allows you to choose from among 6 types of analysis graphs.

- Reference - The “Setup and Calculations” menu option allows you to access background information on the system. The “Data Inventory” menu option allows you to access background information on the data collection. The “History of Changes” menu option allows you to access a log of changes with regard to the data.

- Database – For detailed analyses you can directly access the PeMS database.
Appendix 2: PeMS algorithm for g-factors and speeds

Outline

- Theoretical and empirical evidence of g-factor variability
- The algorithm
- Empirical results and comparison with constant g-factor algorithm
g-factor and speed estimation

- Fundamental relation

\[ v(t) = g(t) \times \frac{\text{count}(t)}{\text{occupancy}(t) \times T} \]
Variation in g-factors between detectors

- **Histogram of mean of g for lane 1 (N = 510)**
  - Percentage distribution of g values with a median of 20.1 feet.

- **Histogram of mean of g for lane 2 (N = 334)**
  - Percentage distribution of g values with a median of 22.3 feet.
Variation in g-factor over time
PeMS g-factor algorithm

- Basic assumption: fixed and known free-flow speed

- Step 1: IIR filter to trace g-factor

- Step 2: corrector to cancel delay.

\[
g_{\text{inst}}(t) = \frac{o(t) \times T}{c(t)} \times v_{\text{free}}
\]

\[
g_{\text{filt}}(t) = (1 - p) \cdot g_{\text{filt}}(t - 1) + p \cdot g_{\text{inst}}(t)
\]
or

\[
g_{\text{filt}}(t) = g_{\text{filt}}(t - 1)
\]

\[
g(t) = g_{\text{filt}}(t) + \left[ g_{\text{hist}}(t + \tau) - g_{\text{hist}}(t) \right]
\]

\[
v(t) = \frac{o(t) \times T}{c(t)} \times g(t)
\]
Empirical results

Speed on lane 4, I-80, May 23rd

Occupancy measurements on lane 4, I-80, May 23rd
Comparison with constant g-factor algorithm

- Comparison based on variation over one day

- Evaluation based on the relative mean error,

\[
Err = \sqrt{\sum_{i} \frac{(v_{est}(t) - v_{real}(t))^2}{v_{real}(t)}}
\]
Conclusion and future work

- Shown empirical evidence of the variability in the g-factor.
- Introduced PeMS adaptive, real-time g-factor algorithm.
- Future work:
  - Free-flow speed
  - How to determine congestion?
Figure: std histogram of g-factor

Histogram of std of g for lane 1 (N = 510)

Histogram of std of g for lane 3 (N = 334)

G factor in feet (median = 1.9)

G factor in feet (median = 3.0)
Figure: std of g-factor
Berkeley Highway Lab

- 12 cameras with overlapping fields of view covering 1.5 miles of I-880
- Video data are processed to obtain position and speed of every vehicle
- Left movie is feature tracker; right movie is grouper
Lane-changing maneuver and shockwave
Microbehavior
Lane changing
Shockwave