Motivation

Is it possible to estimate arterial traffic information from a low-frequency probe vehicle data feed?

Data Feed

A public probe vehicle data sent from transit buses in the city of San Francisco.

Applications

It is successfully shown here that it is possible to use probe data to estimate:
- Signal Phase and Timing (SPaT)
- Travel time statistics along the road
- Queue patterns
- Vehicle trajectory with applications in:

- Signal Phase and Timing (SPaT) Estimation

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  - The key feature of the proposed SPaT estimation approach is estimating the delay between green-initiations ($t_{\text{start}}$) and the moment that a vehicle stops in queue starting at green. This delay is called lost time in queue ($\Delta t_{\text{l}}$):

    \[
    t_{\text{start}} - t_{\text{stop}} = \Delta t_{\text{l}}.
    \]

- We assume the discharge time of a N-sized queue consists of two parts:
  - The interval that it takes the vehicle to start moving after green-initiation ($\Delta t_{\text{travel}}$)
  - The interval that it takes that vehicle to travel all the way up to the stop-bar ($\Delta t_{\text{travel}}$)

    \[
    \Delta t_{\text{discharge}} = \Delta t_{\text{l}} + \Delta t_{\text{travel}}
    \]

- An analytical solution for the queue discharge time ($\Delta t_{\text{discharge}}$) is proposed as given in:

    \[
    \Delta t_{\text{discharge}} = N \sum \text{Headway}(n) = n + l \sum e^{-n+1}
    \]

    which is a linear combination of:
    - saturation headway ($h$)
    - marginal headway ($l$)

- The Multiple Linear Regression model (MLR) is used to estimate these parameters based on the observational data.

Queue Flow Statistics

Trajectory Estimation

We present a method of generating the most likely trajectory based on segment travel time statistics.

We use EM algorithm to obtain segment travel time with maximum likelihood:

- E step: Find the mean and standard deviation of travel time for each segment
- M step: Segment travel times are reallocated such that the sum of the log likelihood function for each update pair (observation) is maximized. It is a Constrained Quadratic Programming (CQP) problem.

\[
\arg\min_{\Delta t_{\text{travel}}} \frac{1}{2} y^T Q y + c^T y \\
\text{s.t. } \begin{bmatrix} \Delta t_{\text{travel}}^T & 0 & \cdots & 0 \end{bmatrix} \begin{bmatrix} t_1 \ - t_{\text{start}} \ 0 & \cdots & 0 \end{bmatrix} = 0
\]

\[
y = \begin{bmatrix} t_1 \ - t_{\text{start}} \ 0 & \cdots & 0 \end{bmatrix} \begin{bmatrix} \Delta t_{\text{travel}}^T \ 0 & \cdots & 0 \end{bmatrix}
\]

We can predict trajectory by assuming a bus follows mean segment travel time. If there is delay, we use the same method to allocate delay into each segment.

Results

We demonstrated that it is possible to estimate, fairly accurately, arterial traffic information by observing statistical patterns in sparse probe vehicle data feeds. A successful experimental implementation is also presented for using parts of the estimated arterial traffic information in a modified test vehicle. This implementation is an important step in utilizing this technology in future vehicles.