Evaluation of horizontal and vertical queueing models:
comparison to observed trajectory data in a signalized urban traffic network

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Objectives

- Introduce the formulation of the Vertical Cell Model (VCM), a cell-based implementation of a vertical queueing model for networks with interrupted flow that incorporates a simple representation of intra-link transit delay and finite link storage capacity.
- Validate this model against a set of ground-truth density and flow measurements derived from high-resolution vehicle trajectory observations on a real urban traffic network.
- Show that VCM performs equally as well as CTM relative to these ground-truth observations.

Vertical Cell Model (VCM)

Designed to simplify the intra-link dynamics of a typical CTM implementation, VCM represents the state of an urban road link as a set of "transit" cells and a single "queue" cell.

VCM Link Model

$$\begin{bmatrix} v_l^1(t+1) \\ v_l^2(t+1) \\ v_l^3(t+1) \\ \vdots \\ v_l^{\tau_l-2}(t+1) \\ v_l^{\tau_l-1}(t+1) \\ q_l(t+1) \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 1 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & 1 & 0 & \dots & 0 & 0 & 0 \\ \vdots & \vdots & \ddots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & 0 & 0 & \dots & 1 & 0 & 0 \\ 0 & 0 & 0 & \dots & 0 & 1 & 1 \end{bmatrix} \begin{bmatrix} v_l^1(t) \\ v_l^2(t) \\ v_l^3(t) \\ \vdots \\ v_l^{\tau_l-2}(t) \\ v_l^{\tau_l-1}(t) \\ q_l(t) \end{bmatrix} + \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 0 \\ \vdots & \vdots \\ 0 & 0 \\ 0 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} a_l(t) \\ d_l(t) \end{bmatrix}$$

Notably, the VCM link model is linear in terms of link arrivals and departures. Linear link dynamics improves computational efficiency and yields analytical benefits for theoretical estimation and control procedures.

VCM Node Model

$$R_l(t) = \nu_l \min\left\{c_l \cdot \Delta t,\ \kappa_l - q_l(t) - \sum_{i=1}^{\tau_l-1} v_l^i(t)\right\}$$

$$S_l(t) = \nu_l \min\left\{c_l \cdot \Delta t,\ q_l(t)\right\}$$

ν_l = number of lanes in link l

κ_l = maximum queue storage for link l

In order to ensure network stability, link sending/receiving functions in VCM are dependent on all elements of link state instead of only those of the last/first cell (as in CTM).

Link Departures: (VCM and CTM)
$$d_l(t) = G_l(t)\min\left\{S_l(t),\ \min_{z \in Out(l)}\left\{\frac{1}{\beta_n^{l,z}} R_z(t)\right\}\right\}$$

Link Arrivals: (VCM and CTM)
$$a_m(t) = \sum_{k \in I_n} \beta_n^{k,m} d_k(t)$$

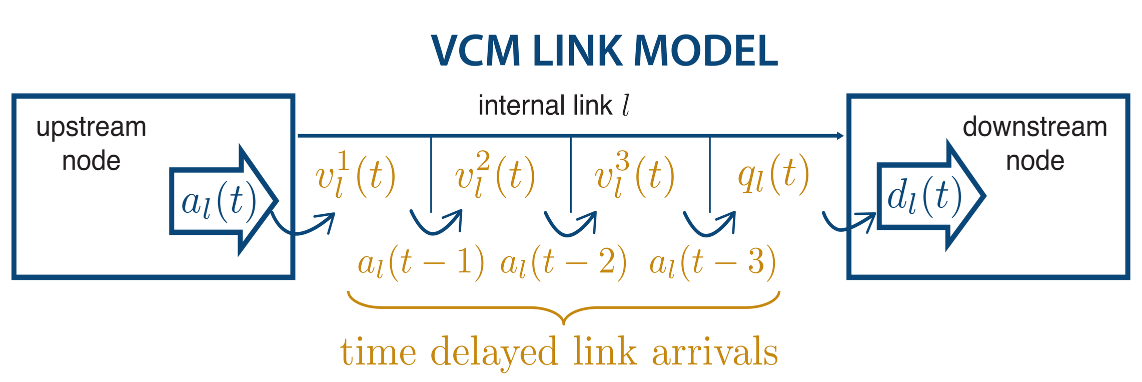

Figure 1 An illustration of the VCM link model

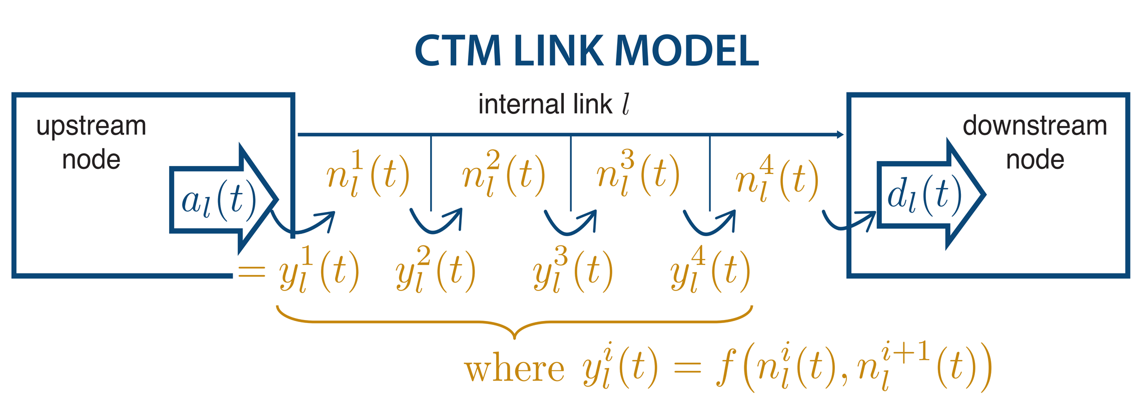

Figure 2 An illustration of the CTM link model

Data

This study makes use of the high-resolution vehicle trajectory data obtained between four intersections of Lankershim Blvd, a busy arterial roadway in Los Angeles, California as part of the Next Generation Simulation Community (NGSIM) project (http://ngsim-community.org/).

- External demands were obtained by aggregating 5-second vehicle counts from the full set of trajectories at relevant network boundary locations.
- Intersection turn ratios were assumed fixed and set equal to the average turning proportion observed over the entire 30 minute data set.
- Signals were timed according to timing sheets provided in NGSIM data documentation.

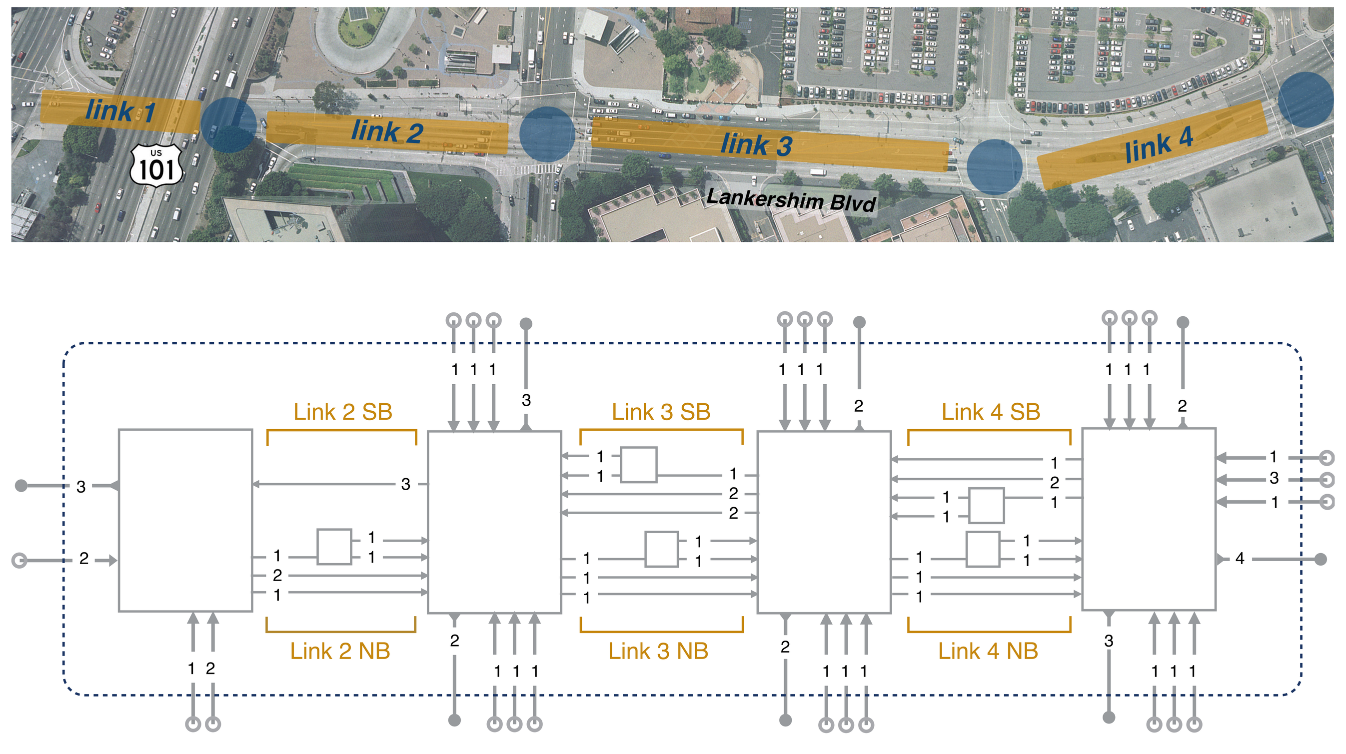

Figure 3 A photo of the Lankershim Blvd data collection site (top) and the graphical representation used in our modeling procedure (bottom).

Model Implementation

Both VCM and CTM were implemented in the *Berkeley Advanced Traffic Simulation* (BeATS) platform using the same network graph (Figure 3) and a cell size corresponding to Δt = 1 second.

Results

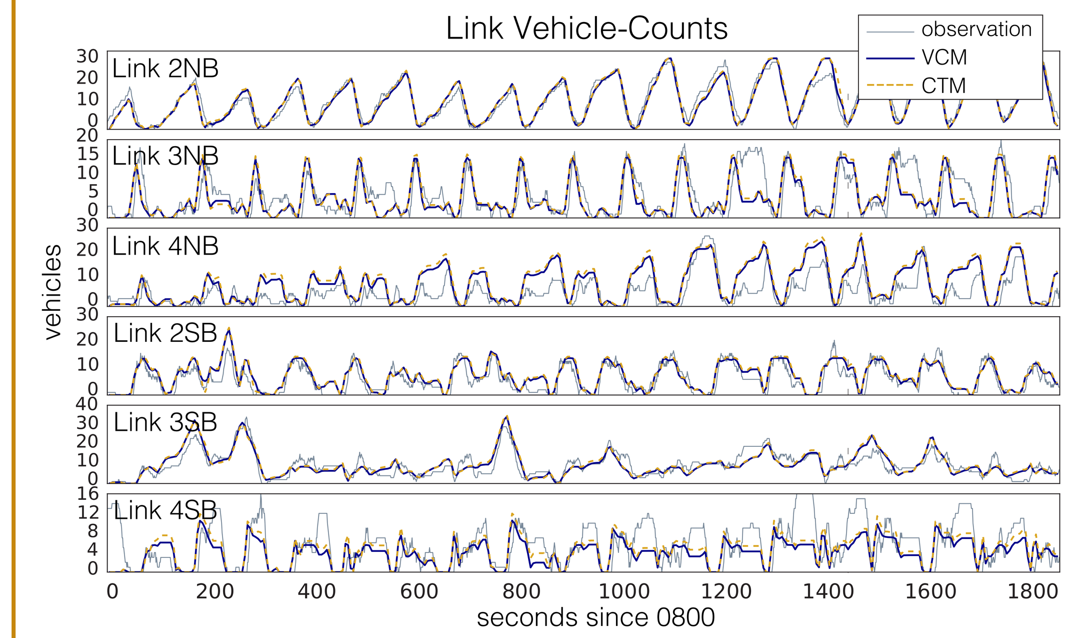

Figure 4 Calculated link vehicle-counts reveal very minor differences beween the vertical and horizonal cell model variants.

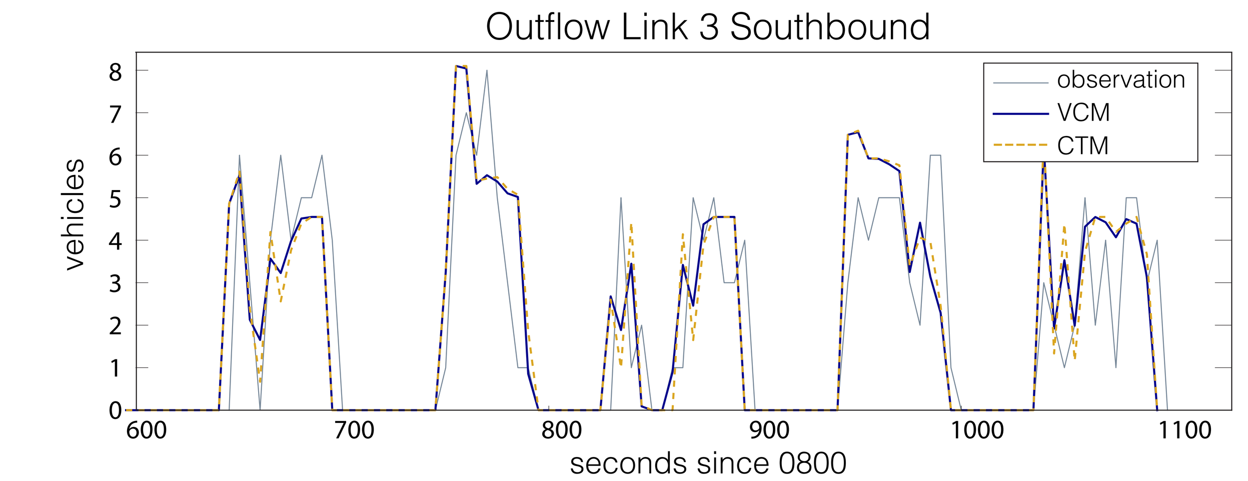

Figure 5 A comparison of modeled and observed link exit flows.

Cumulative Percent Error in Modeled Link Ouput Flows

Link	CTM	VCM
2NB	0.93%	0.84%
3NB	4.53%	4.29%
4NB	1.69%	1.27%
4SB	0.79%	0.76%
3SB	9.25%	9.09%
2SB	6.74%	6.53%

Model error is more sensitive to (shared) misrepresentations of network geometry or physical parameters than to differences in the model dynamics.

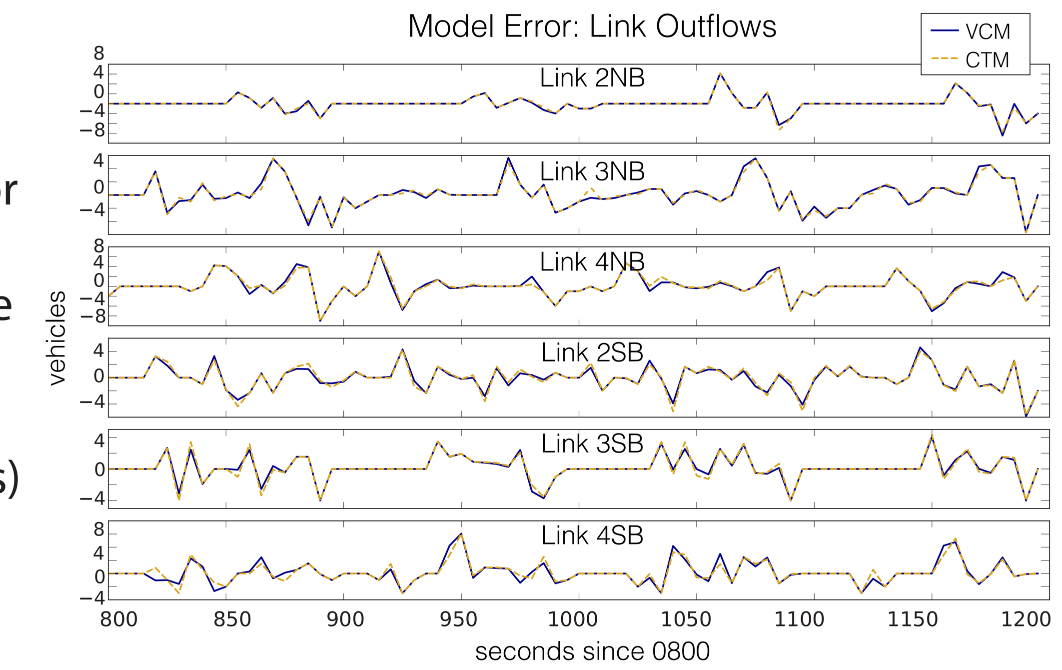

Figure 6 Outflow error for CTM and VCM (relative to 5-second aggregated observations)