# Implications of Information Structure in Control of Urban Traffic Networks

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## Project Objective

Due to the large volume of data generated in traffic, it is computationally, and arguably even technologically, infeasible to inter-connect all sensory and control points for real-time applications. Therefore, it is of interest to study performance of traffic networks under various information structures, i.e., sparse interconnection of control and sensor points. The objective of this project is to study this issue under two complementary topics: (1) traffic management using distributed implementation of variable speed limit, ramp-metering and routing, and (2) private route recommendations or public messages during uncertain situations by a system planner with informational advantage.

## Problem Statement

(1) How to do variable speed limit, ramp metering and routing using only local measurements, and how does the performance compare with centralized operation?

(2) How to generate private route recommendations or public messages to persuade route choice decisions towards social optimal during uncertain situations, and how does it compare with the extremes of not providing any information or simply relaying the situation information?

## Research Methodology

(1) Interpret traffic flow dynamics as a piecewise affine system, use insights from parametric linear program to convert optimal control solution into feedback form, truncate to make it distributed, and evaluate performance through rigorous analysis and simulations.

(2) Cast the problem as an instance of information design, use semidefinite programming for computing solution, explore problem structure to reduce computational cost, and perform simulations for comparison with no information and full information strategies.

## Results

(1) Consider the optimal control problem of minimizing $\sum_{i,k=1}^{N-1} \alpha_i^k x_i^k + \beta_i^k u_i^k + \alpha_i^N x_i^N$ subject to traffic flow dynamics and initial condition $x_i^0$. The cost function can be used to model common performance metrics such as total travel time, travel distance, etc. In this work, we use the Cell Transmission Model, where $x_i^k$ is the density on section $i$ if the freeway at time $k$, and $u_i^k$ is the outflow from cell $i$ at time $k$. Computing optimal outflows $u_i^k$ can be cast as a linear program. This optimal solution can be used to design open-loop control in the form of design variable speed limit, ramp metering and routing to get the optimal outflow profile. However, such an open loop implementation may not be robust to uncertainties. We use multi-parametric programming technique to cast the optimal solution in feedback form $u^*(x)$. Furthermore, this feedback form is piecewise affine.

The feedback form though is centralized, i.e., the control on section $i$ depends on the density on the entire network, which may not be practical for real-time operation. We propose to truncate the piecewise form of $u_i^*(x)$ to get a decentralized form $u_i^*(x_i)$. Our rigorous analysis has identified sufficient conditions on network parameters and coefficients in the cost function under which such a truncation procedure does not lead to any loss in performance, i.e., a decentralized control gives the same performance as centralized control. Even when these sufficient conditions are not satisfied, our simulations suggest that the performance loss due to decentralization may not be significant. Figure 1 illustrates the results from one such simulation study.

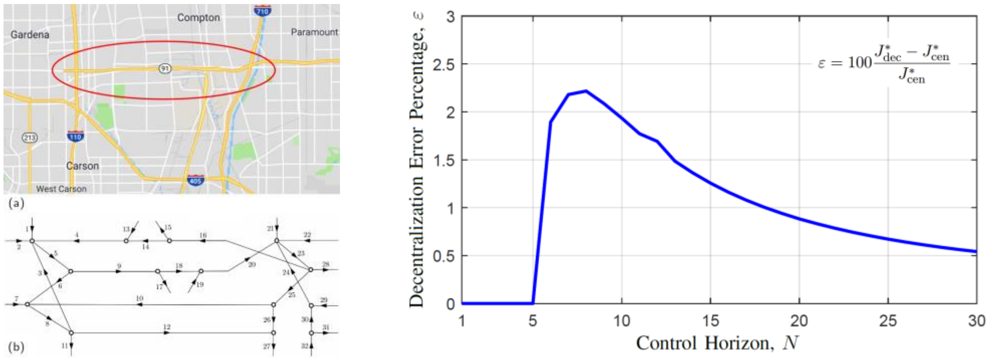


**Figure 1: (left) The map of an area in the southern Los Angeles used in the simulations. (right) Relative performance loss due to decentralization as a function of control horizon.**

(2) Let the link latency functions of traffic network be conditional on network state, which is uncertain for the travelers but known exactly to a system planner. The travelers have prior information about the uncertain state. The planner desires to design a private signaling scheme $\pi$, which maps the network state to randomized private route recommendations to the travelers. A public signaling scheme on the other hand is the one which provides noisy information about the network state. Only a fraction $\nu \in [0,1]$ participates in the signaling scheme and these travelers obey the recommendations, if on an average, they lead to lower travel times than choosing routes on their own based on their prior information about the uncertain state. We show that the problem of choosing an optimal obedient $\pi$, i.e., one which minimizes expected total latency of all travelers is an instance of the well-known generalized problem of moments if the link latency functions depend polynomially on traffic flow. This is the case, for instance, for the Bureau of Public Roads latency function. We develop an exact discretization of the continuous probability representation of $\pi$, to be able to solve the information design problem using open source software. Figure 2 illustrates a sample output of this implementation. We provide a characterization of the resolution of discretization in terms of complexity of latency functions and network structure. Furthermore, while it is known that optimal social cost could *increase* with increased participation rate under a public signal, we provide a reasonable class of private signals under which this does not happen.

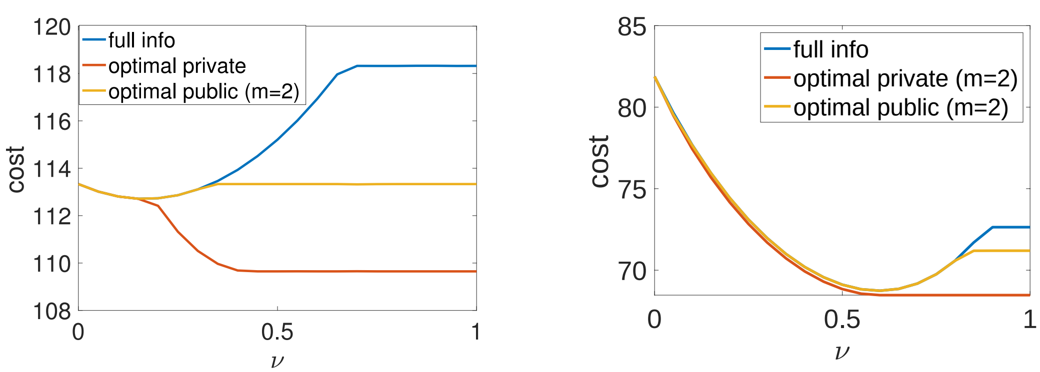


**Figure 2: Comparison of minimum cost achievable under private signals, public signals and full information over two parallel links, under different fraction of participating agents for (left) affine latency functions and (b) Bureau of Public Roads latency function**