Freeway Traffic Modeling and Control (Abstract)

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Traditional traffic modeling and control philosophy divided traffic into two phases: free-flow and congested, and the control intended to bring congested traffic back to free-flow if it is congested. Freeway traffic modeling and control from a new viewpoint intends to view the traffic phases as a continuous spectrum. The control strategy is to keep the traffic at its maximum flow possible, which is determined by freeway section capacity, demand from onramp and flow through off-ramps along a corridor. Traffic modeling and control need to be coordinated along a corridor since traffic is moving forward and shockwave propagates backwards. Traffic at each section affects each other dynamically and serially in both time and space along the stretch of freeway. Freeway corridor traffic flow is limited by bottleneck flow. Previous studies indicated that if the upstream of a bottleneck is congested, the throughput of the bottleneck will drop 5~20% below the capacity depending on the location and geometry etc. A logical control design approach for freeway traffic is to maximize the bottleneck flow.

Cell Transmission Model (CTM) is a discretized version of the LWR model under the assumption of a Fundamental Diagram, which is essentially a nonlinear 1st order density dynamics. METANET model is a 2nd order, which could be considered as a model with added speed dynamics to the density dynamics. Original METANE model has a nonlinear parameterization for the speed control variable, which intends to control the traffic flow on a Fundamental Diagram. Such a parameterization is highly nonlinear and difficult for control design. A simplified METANET Model will be presented, which drops the nonlinear parameterization, which still capture traffic dynamics and is believed suitable for control design due to its simplicity.

Variable Speed Limits (VSL) and Coordinated Ramp Metering (CRM) are main freeway traffic control strategies, which are complementary in functions. Two methods will be presented for combined VSL and CRM to maximize the flow of the recurrent bottleneck which can be modeled as a lane drop or virtual lane drop with weaving effect. The control design for the first method can be simply described as: (a) Assuming a known ramp metering rate for each onramp; (b) using Finite Time Horizon Model Predictive Control to design VSL for each link; (c) VSL design is based on a simplified 2nd order METANET model with density (or occupancy) and mean speed as the state variables. Simulations have been conducted in Matlab with performance measures to evaluate the control strategy quantitatively.

The second method for maximizing recurrent bottleneck flow is to create a discharge section immediately upstream of the bottleneck. The control design strategy is to design VSL based on measurement instead of a model while taking into account the upstream and onramp demand, off-ramp flow, onramp length limit, driver acceptance and equity along the corridor. At each time step, after the VSL design, the 1st order model is linearized, based on which, a Finite Time Horizon Model Predictive Control strategy is used to design a CRM along the corridor. Both macroscopic and microscopic simulation results in Aimsun showed that the control strategy could improve traffic throughput significantly.