DRISI

Caltrans Division of Research, Innovation and System Information

Research Results

Performance Analysis and Control Design for On-ramp Metering of Active Merging Bottlenecks

Design the control parameters for pre-timed and traffic-responsive on-ramp metering of congested merging bottlenecks.

Transportation Safety and Mobility

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Project Title:
Performance Analysis and Control Design for On-ramp Metering of Active Merging Bottlenecks

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Task Manager:
John Slonaker,
Senior Transportation Electrical Engineer
john.slonaker@dot.ca.gov

WHAT WAS THE NEED?

The complex interplay among merging, lane-changing, and accelerating behaviors plays an important role in determining the performance of a congested merging area. Once a merging bottleneck is activated, the flux of exiting vehicles can drop by 10% (about 800 vehicles per hour on a four-lane freeway).

Such a capacity drop can lead to traffic queues and stop-and-go traffic patterns that increase fuel consumption and greenhouse gas emissions. Given a limited budget, a decision support tool is necessary to determine whether a ramp meter is warranted at specific locations; which merge areas should be given higher priorities; whether pre-timed or traffic responsive metering algorithms should be implemented; and what kind of control parameters are the best. Caltrans needs to develop criteria for selecting which on ramps to meter and metering techniques for minimizing congestion on the main line caused by vehicles entering the facility.

WHAT WAS OUR GOAL?

The objective of this research was to analyze the performance of, and design the control parameters for, both pre-timed and traffic-responsive on-ramp metering of congested merging bottlenecks. This method supported the overall goal of increasing the throughput of merging areas near on ramps by providing guidelines for the necessity, priority and technique of ramp metering systems.

WHAT DID WE DO?

The researchers analyzed and designed ramp metering of an isolated merging bottleneck. They used a simple link queue model to describe traffic dynamics with an ordinary differential equation combined with a capacity drop model. They identified the set of equilibrium states and showed that for specific demand patterns there could be two equilibrium states, so there could be a situation in which it is possible to avoid the onset of congestion, but once congested, not possible to dissipate.

The researchers analyzed an example for a freeway segment with two bottlenecks and demonstrated that successful control of some active bottlenecks can worsen the overall road network's performance. This proved the existence of paradoxical behavior in traffic control systems, where the successful control of individual active bottlenecks could actually deteriorate the overall system's performance. Such paradoxical behavior of traffic control systems can lead to wrong investment decisions and worsen traffic congestion and therefore warrants a better understanding. With this in mind, the researchers carried out numerical simulations to compare the total travel times before and after this myopic control strategy and defined the price of myopia to quantify its negative effects.

WHAT WAS THE OUTCOME?

The researchers were able to show analytically the hysteresis imposed by the capacity drop phenomenon. The maximum metering rate for which the capacity drop can be avoided is greater than the metering rate necessary to recover from the capacity drop. This showed the asymmetrical effect of a small disturbance: a small decrease on the upstream demand leads to a small decrease in the flux of exiting vehicles; a small increase, however, can trigger a capacity drop and severely decrease the flux of exiting vehicles. If a disturbance to the system leads to capacity drop, it might not be possible to recover from it unless the upstream demand decreases. This result is general and regardless of the control strategy.

This study definitely established that myopic traffic control strategies can be detrimental to the whole system. It also revealed one underlying mechanism of such a paradox: successful local control activates the downstream, otherwise dormant, bottleneck, and the resulting queue further blocks the upstream bottleneck. Moreover, the researchers demonstrated that the phenomenon occurs under a wide range of conditions in a simple network. A new concept, "the price of myopia," was introduced to quantify such negative effects of myopic control strategies. One insight obtained from this study is that one needs to include all bottlenecks that can be potentially activated by the control strategy. Another insight is that Caltrans may be able to improve traffic flow by creating artificial bottlenecks at certain locations. This study clearly shows that coordinated traffic control is not only beneficial, but also necessary, for a complex road network, as otherwise we may have to pay a price of myopia.

WHAT IS THE BENEFIT?

This project will help Caltrans make decisions on the necessity of ramp metering at particular locations as well as the priority for metering among prospective locations. It will also help practitioners choose which algorithm would be most effective, which parameters to adjust, and how to tune those parameters. This research will lead to a decision support tool that can help to answer the following questions: Is a ramp meter warranted at a particular location? Which merge areas should be given higher priorities, given a limited budget? Should pre-timed or traffic responsive metering algorithms be used? What kind of control parameters are the best? Implementation of optimized ramp metering operations could significantly reduce congestion in, and upstream of, the merging areas near on ramps.

IMAGES

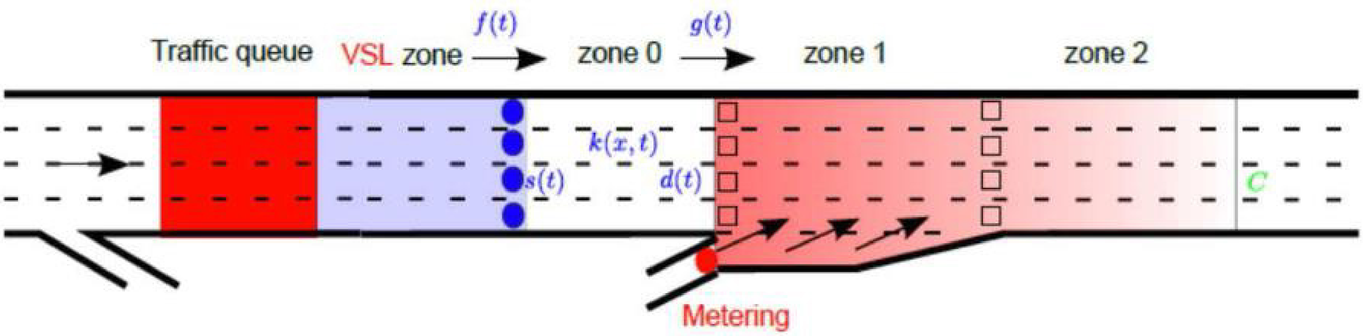

Image 1: An active merging bottleneck

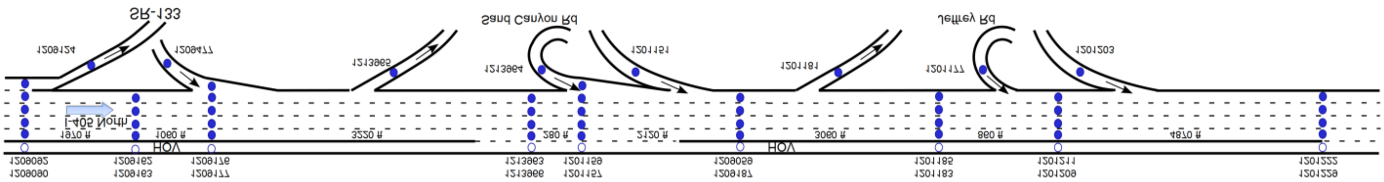

Image 2: Northbound I-405 from SR-133 to Jeffrey Road