CUTC Student of the Year Recognized for Research in Freeway Traffic

Jack Reilly, 2014 CUTC Student of the Year.

Expanding the Nation's transportation workforce is a primary goal of the University Transportation Centers (UTC) Program. Jack Reilly, a former UTC-supported Ph.D. student at the University of California, Berkeley, is one example of how that goal is being met. Reilly, who was awarded the prestigious Student of the Year award from the Council of University Transportation Centers (CUTC) last year, is now a software engineer at Google where he has worked with the Road Traffic team.

The CUTC research was part of the Connected Corridors project, a collaborative effort to research, develop, and test a framework for corridor transportation system management in California. Reilly's contribution pertained to the management of freeway traffic via two distinct control measures: on-ramp metering and variable speed limits. Reilly developed algorithms so that both measures could be deployed in joint, coordinated fashion on freeways of extended physical lengths. The algorithms enable a proactive approach to freeway management by anticipating the metering rates and posted speed limits suitable for later times during a busy rush. This anticipatory feature was made possible by attendant models that project in time the freeway's traffic demands and their potential impacts on congestion levels. *In simulations of a hypothetical but realistic freeway with noisy sensor data, the proactive metering algorithm was shown to reduce delay by up to 3 percent. A strictly reactive metering scheme was found to reduce delay by less than 2 percent.*

Another of Reilly's main contributions was to make the algorithms function in real-time. This was achieved by making use of distributed strategies for optimizing the control measures. Under this decentralized approach, a lengthy freeway is partitioned into smaller, contiguous segments.

The on-ramp metering rates and speed limits that minimize the travel times collectively incurred by vehicles are then jointly determined for each and every freeway segment. The determinations are made for each segment simultaneously.

A challenge occurs because traffic conditions on one freeway segment can affect conditions on others. Imagine, for example, a bottleneck that forms on one segment. The resulting queue may spill over to segments residing upstream. At the same time, the bottleneck may starve downstream segments of flow. This means that the ramp metering rates and speed limits implemented on any individual segment can affect that segment's traffic conditions as well as dictate the control levels most suitable for neighboring segments.

To address this complication, the traffic conditions and control measures at each freeway segment were considered when optimizing the control measures on its nearest neighbors (only). This process allowed for the sharing of useful information across contiguous segments. Yet, the process held the amounts of shared information to manageable levels. In this way, the iterative process of selecting each segment's ramp metering rates and speed limits could converge to yield near-optimal solutions. And this convergence can occur promptly enough to enable real-time deployment.
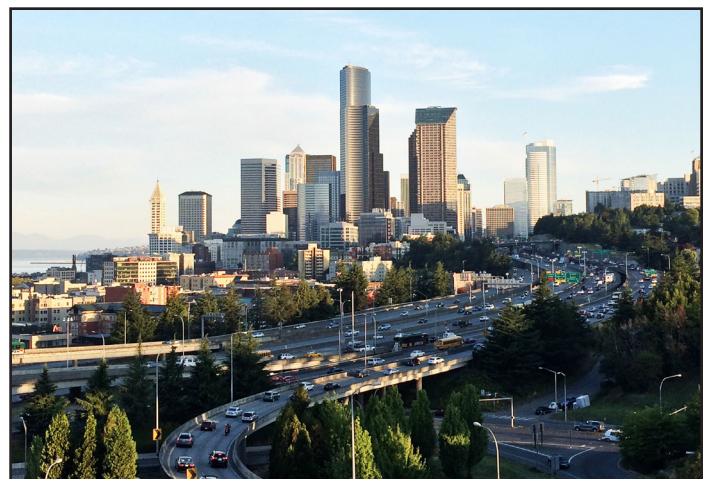
Busy on-ramp in Seattle, WA.

Freeway study site, Interstate 15 southbound in San Diego, CA.

Reilly tested his algorithms via computer simulation. The simulation model emulated traffic over a 20-mile stretch of southbound Interstate 15 in San Diego, California. Simulations were performed for a 170-minute period of a morning rush when traffic became congested. The freeway's traffic demands were forecasted over 25-minute horizons. Metering rates for the site's nine on-ramps and posted speed limits were reoptimized every 17 minutes. To satisfy the requirements of real-time operation, each optimization process was allowed to continue for no more than 10 minutes.

Outcomes of the simulation experiments were quite revealing. For starters, Reilly's distributed algorithms produced total travel times that came to within 1 percent of estimated lower bounds. The latter were obtained using perfect information for initial conditions, including the initial travel demands, and by removing the time limits placed on each optimization process. Other joint strategies for metering ramps and deploying variable speed limits did not hold up nearly as well. One of those other strategies entailed algorithms that did not share information across neighboring segments. Another shared each segment's information with all other segments on the 20-mile freeway stretch. In that latter case, so much computationally expensive information was shared that the optimization processes terminated after performing numerous iterations, without ever converging to good solutions.

Those suboptimal management strategies were predicted to degrade freeway travel conditions as compared to a do-nothing, no-control strategy. For example, the simulation

model predicted that the strategy that shared mountains of information increased total travel times over the no-control option by a factor of more than three. The findings thus seem to offer a cautionary note in regard to freeway congestion management—well-intended, but suboptimal strategies can have a negative impact on traffic.

This is not the only sobering outcome of the simulation experiments. The model further predicted that even the lower bound, best-case metering and speed-limit strategies offered only limited improvements over the no-control option. Total travel times under the best-case scenarios diminished by little more than 1 percent. The findings suggest that when it comes to easing freeway traffic congestion, less than optimal attempts actually make traffic worse while successful efforts may have little effect.

Further details on this work are furnished in two publications coauthored by Reilly and his dissertation advisor, Professor Alexandre Bayen; see:

1. Reilly, J., Bayen, A.M. et al., "Adjoint-Based Optimization on a Network of Discretized Scalar Conservation Laws with Applications to Coordinated Ramp Metering," in *Journal of Optimization Theory and Applications*, vol. 167, no. 2, pp. 733–760.

2. Reilly, J., Bayen, A.M., "Distributed Optimization for Shared State Systems: Applications to Decentralized Freeway Control via Subnetwork Splitting," in *IEEE Transactions on Intelligent Transportation Systems*, vol. 99, pp. 1–9.

About This Project

Jack Reilly received his doctoral degree from the department of Civil and Environmental Engineering at UC Berkeley. Michael Cassidy (cassidy@ce.berkeley.edu) is the Director of the Region 9 University of California Center on Economic Competitiveness in Transportation, which consists of a consortium of six universities in California.