FHWA's Traffic Research Lab (TReL): Searching for Keys to Unlock the Nation's Gridlock

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Traffic engineers in Des Moines, Iowa, had a problem. A freeway diamond interchange built to accommodate modest traffic flows apparently was no longer working. Congestion at the interchange was increasing and the affected citizenry was fuming almost as much as their idling automobiles. Plans were made to raze the existing diamond interchange and construct a massive partial cloverleaf capable of handling heavier traffic loads. But before the first cut was made in the earth, the engineers opted to test their existing interchange using simulation-based traffic analysis tools developed at the Federal Highway Administration's (FHWA) Traffic Research Laboratory (TReL).

In an effort to discover why a freeway diamond interchange in Iowa was no longer working, FHWA researchers at the Traffic Research Laboratory used a microscopic traffic simulator, called CORSIM, to pinpoint the problem. Pictured here is the simulation of the interchange in Iowa.

The result? What began as a modest gambit to determine the feasibility of the project instead resulted in an enormous windfall for the state. Simulations of the diamond interchange's traffic flow using CORSIM, TReL's microscopic traffic simulator, indicated that the problem had more to do with poorly timed adjacent traffic signals than any shortfall in network capacity. FHWA staff, working with the Iowa Department of Transportation, recommended modifications to the existing signal patterns. Traffic flow improved, and the state of Iowa saved the $14 million it would have cost to build the new partial cloverleaf.

This is the kind of success story FHWA anticipated when TReL was born in October 1997 at the organization's Turner-Fairbank Highway Research Center in McLean, Va. The laboratory, part of the Advanced Traffic Management System (ATMS) Research and Development (R&D) Program, was established as a comprehensive experimental testbed and analysis toolbox to facilitate FHWA's complex, multifaceted R&D program.

The state-of-the-art in transportation engineering has advanced dramatically over the last decade, and the application of new and more flexible traffic control devices, software systems, computer hardware, communications and surveillance technologies, and analysis methods has become common place. Nevertheless, the state-of-the-practice has fallen short of achieving its full potential to effectively address and resolve the nation's critical congestion management issues. One reason is that many of these technologies are implemented without being adequately tested. Cities and states are making large investments on the assumption that these systems will work, without any real system-level, predeployment testing by the system vendors. This "good faith" approach has not worked, and as a consequence, advanced traffic control systems continue to underachieve their goals of increasing the efficiency and safety of roadway operations while simultaneously minimizing the adverse impacts of transportation systems on the environment

Today, with limited available right of way and austere budgets, states can no longer rely on construction or untested technologies to solve their congestion problems. As a result, the states are doing more modeling, and they are managing their resources more wisely. It is precisely this kind of innovative thinking and effective resource management that FHWA is trying to promote and support, and TReL is one part of this effort.

TReL Can Help

Inasmuch as research products should be rigorously tested prior to deployment, TReL performs a valuable service. Although designed primarily to support FHWA's R&D needs, it is possible for states and cities to use this laboratory.

TReL combines advanced hardware, software, and communications systems to support the research, development, analysis, testing, evaluation, and integration of transportation management systems and technologies. TReL capabilities include isolated device testing in off-line and online environments, systems integration testing, and Traffic Management Center operations research.

TReL accelerates the pace and effectiveness with which new transportation technologies and systems are researched, developed, and deployed. TReL provides raw data on the characteristics of a simulated traffic network — such as network geometry, traffic conditions, and the presence of controllers and sensors — and then interprets and evaluates that data to determine the operational conditions of the network.

By using TReL's analytical "toolbox," FHWA engineers can predict how the network will operate at some time in the future and can develop and evaluate alternatives. These alternatives might include modifications to traffic signal timings, geometric configurations, diversion/demand

Here, traffic signal controllers are unders simulated preemption.

management options, or other ATMS strategies. The user can then evaluate their operational impact by analyzing the extensive measures of effectiveness available through TReL.

After simulating alternatives and assessing their impact, the user can determine the desirable alternative and then can test its implementation. This process can be stopped, started, repeated, and run concurrently as needed to accommodate the possible operational problems and/or new system deployments that the transportation engineer is investigating.

Traffic Simulation

FHWA R&D has a long history of advancing the state of research and development activity through the application and enhancement of traffic modeling and simulation. This R&D investment has resulted in traffic analysis models — principally the CORSIM microscopic simulation — that represent 30 years of traffic engineering theory, mathematical models, and traffic engineering heuristics. The TReL offers all of the benefits of traffic simulation and many additional capabilities above and beyond what simple simulation can provide. These features make the TReL a unique and powerful testing environment.

A visit to the lab showcases the impressive investment in new technologies being made by FHWA.

“Computer technology has provided us with incredible opportunities to simulate things, like driver behavior, that we never could have done before,” said Henry Lieu, an FHWA research engineer at the lab.

The unique capabilities inherent in the TReL have allowed the FHWA ATMS R&D team to focus its research agenda on new traffic control strategies and to study them in a fashion never before possible. Intelligent transportation systems (ITS) strategies under consideration for research in the lab include advanced signal optimization (using simulation as an adjunct to traditional optimization methods), emergency-vehicle signal preemption, closed-loop traffic control systems, transit priority schemes, integration of at-grade railroad crossing with adaptive control systems, toll operations, and more. Using the capabilities of the TReL, FHWA researchers can now determine the impacts of these new ideas on the capacity and safety of our roadways.

The TSIS Tool

A key tool in TReL’s analytical toolbox is FHWA’s Traffic Software Integrated System (TSIS). TSIS provides a state-of-the-art environment for managing, controlling, and coordinating the application of FHWA’s family of traffic engineering analysis and simulation tools.

More importantly, TSIS provides a common analysis framework with efficient mechanisms for sharing data between traffic engineering tools and standard interfaces for communicating with real-time traffic control systems and hardware devices.

TReL’s Models

TReL has several integrated tools for simulating and assessing traffic conditions.

- CORSIM simulates traffic and traffic control conditions on combined surface street and corridor networks. CORSIM determines how traffic engineering and control strategies impact a prescribed network’s operational performance, as expressed in terms of various measures of effectiveness (MOEs). The MOEs (such as speed and delay) provide insight into the effects of the applied strategy on traffic operations and provide the basis for optimizing the applied strategy.
- TRAFVU is a visualization processor for the CORSIM microscopic traffic simulation system. TRAFVU allows the user to animate traffic simultaneously in multiple views of the traffic network under the same or different conditions. With TRAFVU, the user can visualize the simulated network and analyze the simulation results using several graphical presentation formats.
- PASSER IV is a program for optimizing signal timings on arterials and multi-arterial closed-loop networks. When it is incorporated into TReL’s TSIS, PASSER IV — a product of the Texas Transportation Institute — will be able to obtain the basic network information from CORSIM input files and then update those files with the optimal signal-timing plans. PASSER IV will be the first third-party component available for use with TSIS.

Projects and Activities to Date

Since its creation late in 1997, TReL has already produced impressive results. TReL serves as a major platform for the development, testing, and deployment of the following systems.

Adaptive Control Systems

An adaptive control system (ACS) uses sensors to “read” the characteristics of traffic approaching a traffic signal, and using mathematical and predictive algorithms, ACS “adapts” the signal timings accordingly, optimizing their performance. ACS offers substantial improvements over traditional reactive methods. Using detectors and faster than real-time modeling, traffic volumes and patterns can be predicted, and signal timings can be adjusted prior to the onset of congestion so that the needs of the traveling public are best met.

Several algorithms, called control strategies, have been developed to address different geometric and traffic conditions. These algorithms are incorporated into an overall Real-Time Traffic Adaptive Control System (RT-TRACS) logic that includes a database management system and global control logic.

TReL provides the infrastructure needed to conduct exhaustive, simulation-based, laboratory testing and evaluation of candidate ACS algorithms under a wide range of geometric and traffic conditions prior to field installation and live operational testing. The results of the TReL evaluations have been used to select, refine, and finalize the adaptive control strategies to be used in the field testing and implementation of RT-TRACS.

The RT-TRACS system was initially field tested on the Reston Parkway in Reston, Va., in cooperation with the Virginia Department of Transportation. The before-and-after studies are now complete, and a report on the findings will be published shortly. Several other prototype control strategies are planned for field testing in Seattle, Chicago, and Tucson over the next several years.

Integrated Surveillance Adaptive Control System

TReL also serves as the environment in which to evaluate advanced concepts prior to field deployment. In a current project, TReL is configured to support a hardware-in-the-loop simulation that integrates a video camera sensor with a real-time traffic adaptive signal control algorithm. It also provides a communication interface between the signal control algorithm, the sensor, and the CORSIM simulation engine. TRAFVU, the TSIS visualization tool, is used to provide the visual source for the video camera and to display the effectiveness of the adaptive algorithm.

Based on the computed actual queue lengths provided by the video sensor (versus estimated queue lengths currently used), the control algorithm determines the appropriate signal state for the intersection under adaptive control during each cycle.

Lieu said that the lab is also considering other sensor technologies, including laser ranging, radar, and even satellite technology for wide-area detection methods.

“Years ago, we only studied single intersections,” he said. “Now, with so much development and traffic, we have to look at a much bigger picture, and we now have the tools to do that.”

Controller Interface Device

The traffic signal system community needs advanced tools to evaluate and operate state-of-the-art traffic signal systems. A candidate first tool might afford users a rational procedure for quantifying the benefits associated with various proposed traffic signal system improvements. CORSIM can be used for detailed evaluation from the system perspective, allowing engineers to quantify benefits associated with a variety of alternatives, such as:

- An as-is system.
- Coordinated fixed-time systems.
- Coordinated actuated control systems.

However, due to the large number of traffic signal controller vendors, it is virtually impossible to imagine simulating all of the features of the various possible systems, including proprietary closed-loop and new adaptive control systems. Therefore, a preferable second tool might include a mechanism for off-line testing and tuning of new signal systems before they are deployed.

Because of the potential impact of making a mistake during the conventional online tuning, some modern closed-loop systems are deployed without making many of their sophisticated traffic-responsive features operational. Traffic engineers, who cannot be certain that the adaptive features of closed-loop systems will perform as advertised, are often unwilling to take the risks associated with attempting to make them functional.

To evaluate the impact and sensitivity of the current generation of actuated signal controllers on system performance, the CORSIM simulation program is being used in TReL to obtain comparative measures of effectiveness, such as travel time or delay, for several controller parameters.

An enhancement made to the TSIS package allows physical controllers to be connected to CORSIM. In this hardware-in-the-loop environment, CORSIM provides the microscopic simulation and tabulation of measures of effectiveness.

However, instead of CORSIM emulating controller features, CORSIM sends detector information to the physical controllers and reads back phase indicators. Because CORSIM tabulates performance MOEs, quantitative before/after measurements can be obtained for any hardware conforming to the NEMA TS1 electrical standard for phase outputs and detector inputs. It is this test environment that would allow engineers to verify that desired controller features are operating as expected.

A controller interface device is connected to a NEMA controller.

This hardware-in-the-loop environment was applied to a real test case in Loudoun County, Va., the fastest-growing county in the state. A new hospital requested that the Virginia Department of Transportation (VDOT) grant right-of-way priority to ambulances as they traveled through the nearby intersection of a major east-west artery leading to and from Washington, D.C. This priority is known as “emergency-vehicle signal preemption.” Essentially, the traffic signal can be controlled to give priority to ambulances approaching the hospital. The preemption can throw the entire coordinated traffic control system off balance, wreaking havoc on the hard-earned harmony that comes through signal synchronization and taking a long time for the control system to recover. However, there is a potential benefit of saving lives by getting ambulances to the hospital more quickly.

In conjunction with VDOT, the impact of the proposed signal preemption was modeled in the TReL with VDOT’s actual signal controllers interacting with the TReL microscopic traffic simulator. All nine possible paths that an ambulance might use were defined, and 20 CORSIM runs were executed for each. The resulting MOEs were averaged and tabulated. The results of the study showed that the new hospital’s emergency signal would not adversely affect traffic flow.

“The simulation demonstrated that traffic flow wasn’t heavy enough to be disturbed by the signal preemption,” said Lieu. As a result, VDOT has the confidence to implement the system in the field.

The Future of TReL

The entire ATMS R&D program is centered around TReL. Every ATMS initiative uses TReL to conduct investigations, refine concepts, integrate components, and facilitate the transfer of R&D products from the laboratory to the field. Some of the initiatives that will be evaluated in TReL include:

- Ramp-metering algorithms for recurrent and non-recurrent congestion.
- ITS Deployment Assessment System (IDAS).
- CORSIM re-engineering.
- Incident-detection algorithms.
- Dynamic traffic assignment (DTA) systems.
- Traffic management center (TMC) integration issues.
- Deployment issues of surveillance systems.
- Deployment assistance.
- Virtual traffic management center.
- Pedestrian and bicycle modeling.
- Rail/highway grade-crossing occupancy prediction.

Summary

The TReL accelerates the pace and effectiveness of researching, developing, and deploying new transportation technologies.

Asked to assess TReL’s success to date, Lieu gives the lab a solid “thumbs up.” He noted that the lab has managed to reduce the risks and costs of deployment by simulating much of the work before implementation is conducted.

“If you can do it off-line, you are saving lives and dollars,” he said. “Our ultimate goal here is to close the gap between the state-of-the-art and the state-of-the-practice,” said Lieu. “With TReL, we’re getting there.”

For additional information about TSIS and the work at TReL, visit the TSIS Web site at http://www.fhwa-tsis.com.

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