Integrating Traffic Engineering Field Hardware and Research Methodologies into Transportation Engineering Education

Edward J. Smaglik
Northern Arizona University, Flagstaff, AZ

Abstract

The limited coordination between design and implementation is a significant challenge that must be overcome when implementing a traffic engineering project. Many engineers, particularly recent graduates, may be well versed in traffic theory but may not have the experience to understand the challenges and issues that arise during field implementation. Furthermore, the tools typically used for analysis and design may not provide a complete picture of the range of operational issues that may be impacted by the design. To address this disconnect, a series of lectures and laboratory exercises have been incorporated into coursework at the university level. This material has been demonstrated useful for orienting students to field issues that should be considered during design, and may be useful to introduce other engineers whose responsibilities for traffic issues are not substantiated by their prior engineering experience.

Introduction

As a subset of Civil Engineering, Transportation Engineering has several sub-disciplines, ranging from urban planning and transportation systems analysis to highway design and traffic operations. Materials are available for teaching theory in all of these areas, however, the application of traffic theory into applied traffic operations practice is not well documented by existing textbooks and classroom materials. As such, traditional materials (textbooks) do not adequately cover all matter necessary to provide students with a comprehensive understanding of traffic operations. Supplementing existing textbooks and materials with modules that focus on field hardware and the application of research methodologies provides students with a better understanding of how theory applies to field operations. The objective of this paper is to discuss the implementation of field hardware and research methodologies into transportation engineering, specifically traffic operations, and the benefits of teaching these materials.

Research Methodologies

On-going research continues to change the state-of-the-practice in all fields, particularly in traffic engineering where new technologies such as improved vehicle detection equipment and enhanced controller capabilities can have a significant impact on the signal timing strategies that may be implemented in the field. Existing textbooks provide a basic explanation of signal timing and split allocation, but do not address controller hardware and other critical components that must be well understood for a successful design. This section illustrates how current research theories can be presented in a classroom setting, with examples for signal timing and red light running.

Highway Capacity Manual

The Highway Capacity Manual[1] (HCM) is the primary reference and standard for work in the field of traffic operations[2]. The HCM covers highway operations, arterials, signalized intersections, pedestrians, and other related topics. The HCM presents analysis and design solutions for these subjects that have been developed and refined through applied and theoretical research. The HCM is commonly referred to in traffic engineering textbooks[3], however, the methodologies presented in it are not always carried forth verbatim, and often engineers exercise considerable judgment in its recommended application based on their experience.

In the area of traffic signal timing, the HCM presents a concise, specific methodology for determining the amount of green time required to serve vehicle demand at a signalized intersection. The methodology presented is iterative and time consuming to complete, however it is derived directly from the basic foundations of traffic engineering. In the textbook "Traffic Engineering"[3] by Roess, et. al, traffic signal timing is presented in manner loosely based on the HCM methodology, with assumptions and calculations made on the part of the authors that provide a 'cookbook' type method, as opposed to the iterative method in the HCM.

As part of Civil and Environmental Engineering (CENE) 420: Traffic Signals and Studies at Northern Arizona University, students develop signal timing for a study intersection through three different methods:

1. By hand via the HCM methodology
2. By software, which uses the HCM methodology
3. By hand via the textbook method.

Upon completion of all three methods, the consensus of the class was that while Method 1 was the most time consuming, it was the most rewarding, as the students were able to understand how each value of their design was calculated, and how it related to the underlying HCM traffic flow principles. Method 2 was the path of least resistance, however it is believed that the value of the software was only truly appreciated after the students were forced to work through the methodology by hand, as the software is little more than a calculation tool; it is not a design interface. The students felt that Method 3 with its close ended design was easier to work through, but that it left them with little understanding of how the results fit in with established principles.

During other parts of the course, excerpts from the HCM are used to reinforce basic traffic theory. The use of the HCM methdology, combined with the signal timing example cited above, enhanced the students' learning by establishing a connection between their coursework, current research and the application of the HCM design guidelines in practice.

Red Light Running

Students have an immediate connection with traffic engineering, as almost every one of them has driven a vehicle. One of the topics that has been at the forefront of the news in recent years in Arizona is automated enforcement of traffic regulations[4], with research in the area recently completed by AzTRANS, The Arizona Laboratory for Applied Transportation Research, here at NAU[5]. In CENE 420, students worked with the technology behind the automated enforcement of red light running. Students were provided a data stream from an intersection (Figure 1) equipped to detect red light running vehicles and a video of the approach during the study period. Figure 2 shows a screen capture of the video.

Det	Name	date	time	code	milisec	state		
109	MA2	9/22/2004	5:11:10 PM	100	1525483	1		11.52959
105	MA1	9/22/2004	5:11:11 PM	100	1526784	1		
109	MA2	9/22/2004	5:11:14 PM	100	1529087	1		21.398
105	MA1	9/22/2004	5:11:14 PM	100	1529788	1		
109	MA2	9/22/2004	5:11:15 PM	100	1530689	1		25
105	MA1	9/22/2004	5:11:16 PM	100	1531289	1		
105	MA1	9/22/2004	5:11:17 PM	100	1532591	1		
109	MA2	9/22/2004	5:11:19 PM	100	1533926	1		29.94012
105	MA1	9/22/2004	5:11:19 PM	100	1534427	1		
109	MA2	9/22/2004	5:11:20 PM	100	1535628	1		29.94012

Figure 1: Data Stream

Figure 2: Video Screen Capture

There were a total of 14 incidents of possible red light running during the study period, however the data stream contained about 10,000 lines of data. For this lab, the students were presented with the problem of parsing through the data to determine when these possible incidents occurred, and then verifying the incidents as violations through the recorded video. This task presented the students with an open-ended problem, forcing them to investigate data mining features of Microsoft Excel that previously many of them had never used.

Field Hardware

Field hardware is an area where vendors continue to introduce new products, both to address current functions in a new way and to enhance the capabilities of existing systems. Textbooks rarely address field hardware, partly due to the rapid changes in the field. However, a good understanding of field hardware is critical for engineers who design and operate the traffic systems.

This section provides learning modules that may be used to give students an understanding of the field hardware that is used in traffic signal systems. Learning modules address system components, both inductive loops for vehicle detection and suitcase testers for signal control, as well as an integrated understanding of intersection control through hardware-in-the-loop. The visualization capabilities of hardware-in-the-loop simulation provides a valuable tool not only for education of future engineers, but also for testing new components and signal timing plans, and for illustrating the value of improved signal timing to the public and policy makers.

Vehicle Detection

The majority of signalized intersections operate under actuated control. In actuated control, vehicles are detected and this information is relayed to the signal controller, a small computing device which determines the sequence and duration of green intervals for all movements at an intersection. A variety of vehicle detection technologies are available for use, with inductive loop detection as one of the most widely deployed technologies.

With inductive loop detection, a vehicle passes over a wire loop in the roadway and the steel in the auto body changes the inductance in the loop, indicating that a vehicle is in the detection zone. There are several variables to be considered when setting up and operating an inductive loop detector. Calibrating the detector with these variables properly is imperative for correct operation of the detection zone, as well as for understanding how vehicle traffic interacts with the detector.

To accomplish this in CENE 420, students work with a loop detector demo box, shown in Figure 3. This demo box contains two inductive loops and an amplifier card. The loops are smaller than ones implemented in the field (a matchbox car is used to trigger them in this lab), but the amplifier card is identical to that used in a field installation.

Figure 3: Loop detector demo box

Students walked through the technical operation of the loop, experimented with the different features of the device, and worked through the operation of the device in advanced mode. At the end of the laboratory, the students felt fairly comfortable with operating this piece of equipment.

Traffic Controller

The traffic controller is the device that controls the sequence and duration of green intervals at a signalized intersection. Proper programming of this device is essential for the safe and efficient movement of traffic at a signalized intersection. In CENE 420, students work through a list of programming instructions for a traffic controller. This traffic controller is connected to a suitcase tester. The lab setup is shown in Figure 4.

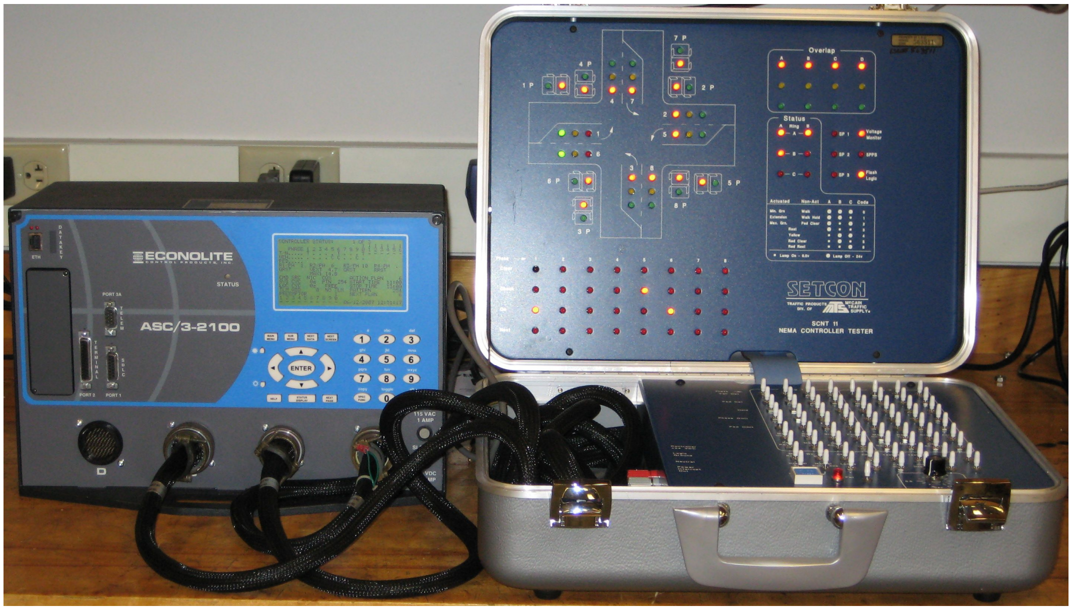

Figure 4: Traffic controller with suitcase tester

The suitcase tester provides immediate confirmation of controller input and output, mimicking the operation of a field intersection. Working with this controller ties together much of the material learned throughout the semester, including the signal timing plans and vehicle detection devices discussed earlier. In addition, it provides the students with an appreciation of the limitations of the field hardware. Even if the student works in design and never touches a field device again, he / she will have a basic understanding of the capabilities and limitations of the device, and be able to apply this knowledge during the design process.

Hardware-in-the-Loop Simulation (HITL)

There are many different manufacturers of traffic controllers, and the algorithms inside each one operate differently from each other, although they all have the same end result, which is controlling traffic. When retiming traffic signals (either in a real-world or classroom setting), it is desirable to use a simulation package (such as VISSIM or CORSIM) to observe the impact of the new timing values prior to implementation. Because of the proprietary nature of traffic signal controllers, these simulation packages contain modules that emulate traffic controllers. These simulated controllers do not contain all the features of a field controller, nor do they make their decisions in the same manner. As a result, it is desirable to interface a field traffic controller with simulation to emulate proper interaction between simulated traffic and traffic control devices[6,7]. Data flow in this type of simulation is shown in Figure 5.

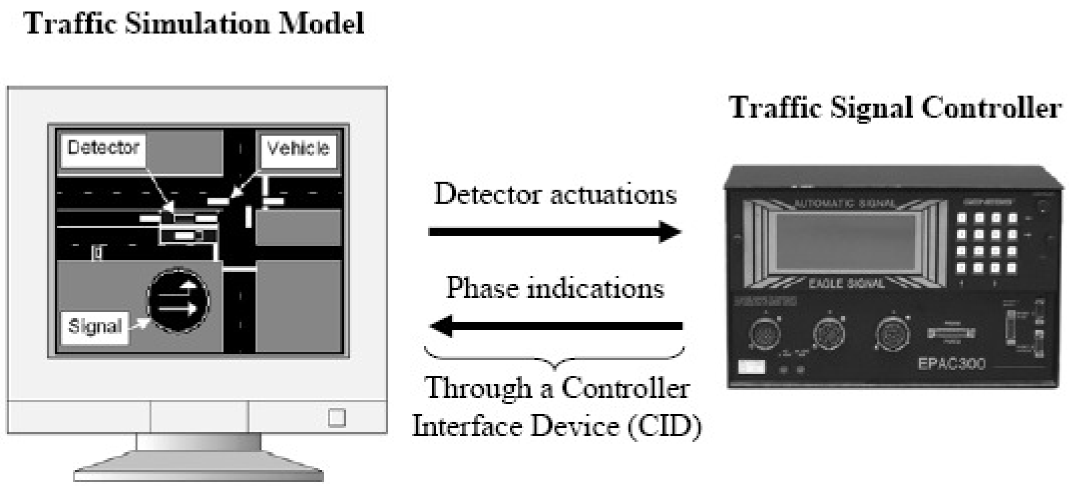

Figure 5: Hardware-in-the-Loop simulation data flow[7]

In a classroom situation, there are several benefits to working with HITL. First, students are provided with real-time feedback on timing plans they have developed. Sensitivity analysis of calculated timing values can be done quickly, empowering the students with the ability to investigate the impact of many variables in a short period of time, and visualize the impact of those changes. Second, because this utilizes field controllers, students spend additional time working with field hardware, strengthening their skills with the device, as well as the connection between design and implementation discussed previously. HITL will be implemented in Spring 2008 as part of CENE 545: Advanced Traffic Signal Systems.

Conclusion

This paper has documented one way in which applied research methodologies and traffic control field hardware can be integrated into transportation engineering coursework to provide important benefits.

- The integration of applied research methodologies into laboratory work provides students with an appreciation for the application of theory in real world application.
- Working with field hardware components, including inductive loop detectors and suitcase testers, allows students the opportunity to appreciate the capabilities and limitations of the hardware which their designs will utilize.
- Hardware-in-the-Loop (HITL) simulation, a traffic simulation methodology using an off the shelf traffic controller, simulation software, and an interface device between the two, enables students to visualize the impact of traffic operations caused by different permutations of their design. In addition, HITL is the state-

of-the-practice technique used by research agencies for conducting traffic simulation.

These materials in the classroom enhance the educational experience in the following ways:

- Provide a connection between theory and real-world application.
- Help produce a graduate with a better grasp of the challenges of design implementation by forcing the student to grapple with field constraints.
- Provide hands-on experience with field hardware.

These modules have proven very useful for engineering students, and may also be useful for practicing engineers whose responsibilities in traffic engineering are not supported by previous coursework or experience. Most civil engineering undergraduate programs provide a strong foundation in traditional civil engineering areas such as structures and materials, but relatively few undergraduate programs have courses that focus on traffic operations. Those programs may find these modules particularly useful.

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[1] Transportation Research Board. *Highway Capacity Manual*, National Research Council, Washington, D.C., 2000.

[2] Smaglik Edward J., A. Sharma, D.M. Bullock, J.R. Sturdevant, and G. Duncan, “Event-Based Data Collection for Generating Actuated Controller Performance Measures," Transportation Research Record, TRB, National Research Council, Washington, DC, TRB Paper ID# 07-1094, in press.

[3] Traffic Engineering (Third Edition) by Roger P. Roess, Elena S. Prassas, and Willian R. McShane, copyright 2004, Prentice-Hall, Inc.

[4] Associated Press. *Arizona Plans to Install More Speed-Enforcement Cameras*. (http://www.azcentral.com/news/articles/1122speed-ON.html), Accessed 02.07.08)

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[7] Balke, Kevin, et. al. “TTI’s Hardware-in-the-Loop Traffic Signal Controller Evaluation System.” FHWA/TX-05/5-1752-01-1, August 2005.