Integrating Active Learning with Simulation: Development and Testing of a New Approach to Learning Signal Timing

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Submitted for Presentation and Publication to:
Submission date: 28 July 2008
Total word count: 7063: Word count: 4063, Graphics count: 12 (3000)
ABSTRACT
This paper reports on the development and assessment of novel traffic engineering education tools that are based on educational models that favor laboratory or hands-on type learning. The mobile signal timing training tool (MOST) presented in this paper is a new paradigm in two respects. First, it involves hands-on experience with “real” traffic controllers. This is important because many entry level traffic engineers have had little direct experience with a traffic controller. The hands on experience provides those traffic engineering professionals with the opportunity to experiment with different control plans and test different scenarios in the office prior to field implementation. Second, the course material has a strong technical foundation, based on traffic flow fundamentals, which can be evaluated using a high quality simulation environment. A significant benefit of this approach is learning the interaction between intersection design parameters and different traffic flow characteristics.

The assessments that were conducted during the classroom testing of the course materials indicated that the most dramatic improvements were observed in the group with the highest proportion of signal technicians. Groups with large representation of engineers showed almost as large increase in knowledge. When tested in a classroom environment with undergraduate civil engineering students, the course materials showed high teaching efficiency as indicated by exams scores and students’ self assessment survey results. This educational tool has quantitatively demonstrated that the educational model used is an important component in signal timing education.
1. INTRODUCTION AND BACKGROUND
The National Transportation Operations Coalition (NTOC) has issued report cards based on self assessments of traffic engineers throughout the country of their traffic signal timing programs: grades remain at “D”. A grade of “D” means that agency’s programs to support efficient maintenance and operations of traffic signals are not as effective as they could be [1]. It is estimated that most of the nation’s traffic signals, or over 272,000 signals, needed some sort of timing or operational improvement.

Several challenges have contributed to this problem of poorly timed or operated traffic signals, with agencies, manufacturers, and universities sharing the responsibility. State and local agencies have reduced funding to provide the support needed to retime their traffic controllers. The traffic control industry tends to use manufacturer specific terminology and unique features that limit the ability of the education and training community to educate and train end users, whether practicing professionals or university students, on good operations of traffic signal controllers. Manufacturers tended implement NEMA and other standards in different ways, often using different terminology for what are seemingly common and well-defined traffic control parameter. Universities and other training institutions have also contributed to the problem. Most university transportation engineering classes typically cover fixed time equivalent traffic signal University transportation engineering classes typically cover fixed time equivalent traffic signal operations and optimization models with little or no relationship to the operation of actuated traffic signal controllers. Furthermore, it is very difficult for universities to provide realistic and safe “hands-on” laboratory instructional facilities [2].

Several recent initiatives are addressing this problem. The Institute of Transportation Engineers (ITE) has established an objective of “reducing congestion and delay by regular retiming of traffic signals” in the national dialogue on transportation operations. The FHWA has released a video [3] designed to motivate local elected officials to implement traffic signal management. A consortium of state departments of transportation, universities, and technology transfer centers met together in Portland, Oregon in September 2002 to identify education and training needs for traffic signal timing in the Pacific Northwest. In preparation for the workshop, a survey was conducted of ITE members in Idaho, Washington, and Oregon regarding training needs. Even though this was a diverse group of transportation professionals that included designers, planners, and operations personnel, 53 percent of the 328 survey respondents identified a need for training in signal timing and control as a high priority [4]. Workshop participants identified topics for engineering professionals, engineering technicians, and university students including signal timing plans, traffic signal control systems, signal hardware and software, operating parameters of traffic signal controllers, advanced traffic signal control systems, theory behind traffic operations, and traffic signal optimization and simulation models [5]. In an effort to improve learning in these areas, FHWA has published its first ever guide to traffic signal timing, a handbook that synthesize current practice [6].

While there have been several new short courses that focus on signal timing, few are based on the educational paradigms focused on the learner, going by such names as process education, active learning, and problems-based learning [7]. Two such programs have been developed by the University of Idaho and its various team members.
In summer 2000, the University of Idaho began offering a one-week workshop on traffic signal timing for university level students. The objective of the workshop was to provide hands-on experiences with the design of traffic control systems, and particularly the understanding of the traffic controller by learning to use and program the controller. A simulation environment known as hardware-in-the-loop (HILS) was used to provide students with a means to experiment with traffic signal timing plans with a traffic controller that was literally “in the loop” with a microscopic traffic simulation model. In this way, students could observe the results of signal timing plans: traffic flows and levels of performance [8]. Since summer 2000, the workshop has continued to evolve and has now served more than 70 students from 30 universities.

As the workshop became more widely known, there was an interest in offering it in other locations, making its delivery more mobile. A trial delivery was held in Jackson Hole, Wyoming in 2003, where we transported 10 desktop computers, controller interface devices (CIDs), and traffic signal controllers for a two day workshop for young professionals.

While this experiment was successful, we recognized the need for a wider exposure of the course without the challenges of transporting an entire laboratory to remote locations. In 2004, the Federal Highway Administration funded a four year project, led by the University of Idaho, with partners from Purdue University, the University of Tennessee, PTV America, and Econolite Traffic Control. The focus of this project was to develop a set of laboratory experiments that would be conducted within a realistic simulation environment, but without the constraints of having to move a significant amount of laboratory equipment. This paper reports on the development of the mobile traffic signal timing course (MOST) and the tests that have been conducted with the course thus far.

This paper includes four sections, including this introduction. Section 2 describes the two basic components of MOST, the laboratory materials and the simulation environment. Section 3 describes what the project team learned during a set of classroom tests of the materials and simulation environment. Section 4 provides concluding thoughts.

2. MOST MATERIALS AND SIMULATION ENVIRONMENT
MOST provides an experience-based learning environment for traffic signal systems that incorporates both realistic traffic modeling and realistic traffic signal controller operation. The training materials are focused at three levels, university civil engineering students, transportation engineering and practicing professionals, and transportation technicians. The MOST training materials have been developed in the form of case studies based on “guided uncertainty” in which students are encouraged to learn critical thinking and problem solving skills based on realistically-simulated intersection or arterial operations. This emphasis is similar to that used for the development of the Highway Capacity Manual Applications Guide [9], in which students are challenged with open ended problems to learn how to apply concepts of traffic analysis.
Five goals were established for MOST, including:

1. increasing engineers’ knowledge of the controller timing parameters that can significantly impact intersection performance, but that are not addressed in optimization models,
2. increasing engineers knowledge of field implementation issues relating to traffic signal timing,
3. increasing knowledge of efficiency and safety issues relating to traffic signal timing,
4. increasing understanding of the effect of traffic variation effects on performance, and
5. improving understanding of the interaction of detector design parameters and signal timing parameters.

2.1 The Simulation Environment

Historically, most university traffic signal education efforts have concentrated on simulation environments that provide reasonably good modeling of vehicle dynamics, but poor modeling of traffic controller operation [2]. In contrast, most vendor based training efforts consider the details of controller operations, but have not incorporated any significant vehicle modeling so that students can learn about the effects of their timing plans. Each of these approaches has had modest success, but neither approach has provided a comprehensive learning environment in which students can learn about both the controller operations and its effect on traffic performance.

Recent hardware-in-the-loop simulation-based educational efforts underway in Arizona, Idaho, Indiana, Tennessee, and Texas are designed to bridge this gap [10]. The vision for MOST is an educational environment that includes a realistic simulation of the operation of an actuated traffic controller consistent with field conditions, and that provides practicing professionals and university students alike with the opportunity to raise their understanding and level of practice concerning the implementation of traffic signal operational parameters at both isolated intersections and coordinated systems. Better signal timing can be achieved by better understanding of the finer points of signal timing and related design issues.

To achieve this vision, two components are required. First, a laboratory environment is needed that provides the opportunity to experiment with traffic control system parameters in a systematic manner, and in a realistic environment, without the dangers involved with students changing timing parameters in the field (and possibly causing crashes or significant traffic congestion). A simulation environment also allows the student to vary detector locations and settings, something that is difficult to do in the field. Second, to make the laboratory experience most effective and reach large numbers of students, it needs to be mobile, to come to the locations of the professionals or students who desire to improve their skills with and understanding of traffic control systems.

The simulation environment used in MOST includes two components, the VISSIM microscopic simulation model and the NTCIP compliant Econolite ASC/3 virtual controller, as shown in Figure 1. This environment is known as software-in-the-loop simulation as a software version of the Econolite ASC/3 controller is used. Students don’t need to know how to run VISSIM as the MOST software manager (top of Figure 1) provides an intuitive interface from which the simulations are run.
Figure 1. MOST simulation Environment
2.2 The Course Structure
A large body of research conducted during the past ten years in engineering education and pedagogy suggests that experiential learning and experimentation provide significantly better outcomes for students than standard lectures and demonstrations. Smith [11] describes the ideal learner as one who is active and is involved in the learning process by asking questions, teaching others, or participating in hands-on activities. He showed that these learners more often develop a comprehension of the ideas and concepts of the material being presented and don’t just memorize the facts being presented. He concludes that active learners are more often able to apply the learned skills to new situations.

Other research supports this concept of more actively involving student participation in the learning process. A study that included a survey of more than 4000 adult learners from a variety of backgrounds who participated in a metric training project at the University of Tennessee Transportation Center [12], identified the hands-on exercises as very useful and often described how much fun they had learning the material in this format. Kolb [13] suggested that technical and hands-on types of learners prefer to be taught using games, exercises and small group discussion.

Two concepts were critical for the MOST team in developing the course structure and materials. First, it must be learner-centered. Education must be focused on the learner’s needs, preferences, and interests, not those of the instructor, organization, or subject matter. Second, individuals learn or change most easily when they actively engage in the learning process. Education must facilitate active learning. This implies hands-on and minds-on involvement in learning.

Both concepts were fundamental to the MOST course materials. These materials consist of a set of structured laboratory exercises that enable students to learn the fundamental principles of signal timing operations through experimentation and testing. It is possible that many students will have learned basic principles of traffic signal timing during their professional experiences, in some cases the wrong principles or an incorrect interpretation of the correct principles. The laboratory environment allows them to test their approaches against those to be demonstrated in the course. In some cases, the course may actually be improved as a result of the feedback of students’ field experience into the laboratory environment.

MOST is designed to be offered over a three day period or as part of a semester long university course. This time frame provides a balance between a long list of material that might be presented in such a course and the difficulty that most potential students have in devoting a longer period of time to a single training activity. This time frame is also consistent with the available course development resources. The course structure anticipates additional modules being developed following the basic modules that have already been developed.

MOST includes seven laboratory exercises, as shown in Table 1. These laboratory exercises form an integrated package of building blocks focusing on how a series of well designed isolated intersections can be effectively operated as a system. The exercises start with a single intersection approach and build towards a fully actuated intersection. Once, the basic concepts of a well operating intersection are presented, two intersections are put into a coordinated system in order to understand the proper operation of coordinated signals. The coordinated system is then
expanded to illustrate issues with both close spacing and high traffic volumes. The remainder of this paper focuses on Laboratories 2, 3 and 4.

Table 1. MOST course structure

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>Learning objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Demonstrate an example of the problems being addressed and the MOST traffic signal simulation and control environment</td>
</tr>
<tr>
<td>2</td>
<td>Understand impact of detector and timing parameters designed for cross street at isolated intersection</td>
</tr>
<tr>
<td>3</td>
<td>Understand impact of detector and timing parameters designed for arterial street at isolated intersection. Introduction to volume density parameters</td>
</tr>
<tr>
<td>4</td>
<td>Understand signal timing issues at a high speed isolated intersection</td>
</tr>
<tr>
<td>5</td>
<td>Understand signal timing issues for isolated intersection with high volumes and heavy directional movements</td>
</tr>
<tr>
<td>6</td>
<td>Understand offsets (and related parameters) for well-spaced two intersection system</td>
</tr>
<tr>
<td>7</td>
<td>Understand offsets (and related issues) for irregularly-spaced oversaturated intersection system</td>
</tr>
</tbody>
</table>

2.3 Learning Objectives

The goal of laboratory 2 of MOST training materials is to develop a detector design (the length of the detection zone) and timing design (minimum green and passage time parameters) for a cross street at an isolated intersection. The learning objectives for this laboratory are to:

1. Understand the relationship between detection zone length, detector location, passage time, and minimum green time on the operation of a phase.
2. Design the duration of the passage time given the design parameters for length and placement of the detector.

The goal for laboratory 3 is to develop a timing plan for a signalized intersection (including passage time, minimum green time, and pedestrian times) with moderate traffic volumes. The laboratory includes four exercises, each based on something that the student must do in order to learn the material:

1. Evaluate the effect of the minor street passage time setting on the efficiency of major street and intersection operations.
2. Evaluate and compare the operation of the intersection with low and high values of passage time and understand the consequences of both alternatives.
3. Evaluate the effect of minimum green time on approach and intersection delay.
4. Design pedestrian timing parameters using MUTCD procedures.

The goal of laboratory 4 is to develop a detector design (location of detection zone) and timing design (minimum green and passage time parameters, as well as volume-density parameters) for the arterial street approach of an isolated intersection using advance detection. The learning objectives for laboratory 4 are to:
1. Analyze the performance of a high speed approach when advance detection is used.
2. Design the minimum values of minimum green time and passage time required when advance detection is used.
3. Identify issues associated with setting minimum green time when advance detection is used and why it must be supplemented with either stop bar detection or the use of volume-density variable initial setting.
4. Design a timing plan that includes volume density variable initial parameters to improve the operation during initial queue service time.
5. Design a timing plan that includes volume-density variable extension parameters to improve the operation after the initial queue is served.

3. WHAT WE’VE LEARNED FROM CLASSROOM TESTING

Four stages of testing have been followed for the MOST course materials, as shown in Figure 2.

- Stage I included verification of the developed materials to examine time allocation, input, and consistency of discussion with simulation output.
- Stage II of the testing included technical review by the project technical oversight committee (TOC).
- Stage III consisted of an expert panel review, including a qualitative assessment focusing on technical appropriateness, delivery methods, and other technical issues.
- The fourth and final stage of testing consisted of a qualitative and quantitative assessment focusing on the course learning objectives.

The results presented in this paper cover the Stage III and Stage IV testing for laboratories 2, 3, and 4 of the MOST course materials. Testing for these three labs was done for two different groups. The first group included a total of 31 professionals (engineers and technicians) from Idaho and Indiana in three workshops. The second group included 42 university students (juniors and seniors) in the Fundamentals of Transportation Engineering class offered at the University of Idaho in Spring 2007.

3.2 Experience and Preknowledge of Workshop Attendees

Three workshops were conducted. Figure 3 and Figure 4 show the characteristics of the workshop attendees. In the initial workshop, conducted in Moscow, Idaho in March 2007, four of the 11 attendees (36.4 percent) had less than two years experience working with traffic signals, while five have more than 8 years experience working with traffic signals (45.5 percent). The two workshops conducted as part of the Stage IV testing had a different cross section of attendees. The majority of attendees (60 percent) at the workshop conducted at Purdue in May 2008 had long experience working with traffic signals (8 years or more). By contrast, at the workshop conducted in Boise, Idaho in June 2008, 60 percent of the attendees had less than two years experience working with traffic signals.

The workshop conducted in Moscow in March 2007 had five signal technicians, representing 45.5 percent of the attendees. During the two workshops conducted as part of the Stage IV testing, however, 90 percent of the attendees were practicing engineers.
Stage I - Verification
Time allocation, input files, discussion, etc.

Stage II - Technical Review/Expert Panel Feedback
Project Technical Oversight Committee: Qualitative Assessment focusing on technical appropriateness, delivery methods, etc.

Stage III – Initial Testing
ITD Staff: Workshop February 2007
College Students: Spring 2008
Quantitative assessment focusing on learning objectives – Quantitative assessment pre-and post workshop interviews

Stage IV – Pilot Workshops
Indiana DOT Staff: Workshop May 2008
ITD staff: Workshop June 2008
Quantitative assessment focusing on learning objectives – Quantitative assessment pre-and post workshop interviews

Figure 2. MOST course testing procedure

Figure 3. Characteristics of Workshop attendees

Figure 4. Characteristics of Workshop attendees

Figure 5 shows the pre-knowledge of the attendees in the topics covered in laboratories 2, 3, and 4. These results are based on a pre-workshop self assessment shown in Figure 6. The first workshop conducted in Moscow had the highest proportion of technicians attending and the lowest level of pre-knowledge. The Purdue workshop attendees, by contrast, had the highest composition of engineers and the highest level of pre-knowledge.
Figure 5. Level of pre-knowledge for workshops’ attendees

Figure 6. Before/after self assessment tool

Figure 7 shows the correlation between years working with traffic signals and level of pre-knowledge for traffic engineers and signal technicians. The graph shows a clear trend, the level of pre-knowledge level increases as the experience increases. The highest pre-knowledge level seems to be achieved by people with 8-12 years of experience. Signal technician, even with more than 20 years experience working with traffic signals, showed low value of pre-knowledge.
level. This is expected as most of the subjects covered in the lab materials are fundamental and analytical based subjects.

3.3 Workshop – before and after evaluation results

The results of the before and after evaluations are summarized in Figure 8 and Figure 9. These results are based on the pre-workshop self assessment qualitative measures shown in Figure 5. In the initial workshop, the course materials were covered in a two-day workshop. Day 1 included introduction of the MOST simulation environment as well as Lab 2 materials. Day 2 included the remaining part of the lab 2 and lab 4 materials. In the two workshops conducted as part of the stage IV testing, the lab materials were covered in a one-day workshop. Figure 8 shows the results of the before and after self assessment tool for the learning objectives for labs 2, 3, and 4. The results show that, on a scale from 1 to 5 (see Figure 6), the incremental learning benefits gained from the initial workshop ranged from 1.7 to 2.2 with an overall average value of 1.9. This relatively high value shows the effectiveness of the course materials in achieving the laboratory learning objectives. For the Purdue workshop, the incremental learning benefits ranged from 1.1 to 1.3, with an average of 1.2. For the Boise workshop, these values were 1.2, 1.6, and 1.5, respectively.

Figure 9 shows the average learning achievements for workshop attendees plotted against the level of attendees’ pre-knowledge. The level of learning achievement decreases as the level of pre knowledge increase. Workshop attendees with good prior knowledge of the topic covered in the workshop had little possible incremental benefits, thus scored relatively low average learning achievement. Workshop attendees with low to moderate level of prior knowledge (level of prior knowledge 1.5 to 2.5) had enough background to be able to learn topics covered in the workshop, and were able to benefits significantly from the materials covered in the workshop. Workshop attendees with very little prior knowledge (level of prior knowledge of 1.0 on a scale of 5) showed mixed levels of benefit from the workshop materials. Their learning achievement levels ranged from 1.3 to 2.8.
Figure 8. Before/after qualitative assessment
3.4 Classroom Testing Results

Lab 2 and Lab 4 were also tested in a university classroom environment. Forty-two students (34 male and 8 female) who were enrolled in the Fundamentals of Transportation Engineering class in Spring 2007 used the laboratories materials as part of two three-hour labs. A short (15-minute) multiple choice exam was used to provide a quantitative assessment of the course materials. In addition, students were asked to provide a self assessment of their post-workshop level of knowledge of the materials covered as well as their qualitative assessment of the course materials using a scale similar to the one shown in Figure 6. The results are presented in Table 2 and Figure 10. Average exam score ranged from 58.3% to 81.2%. The standard deviation of the exam score ranged from 16.6% to 24.7%. When exam questions are related to the labs’ learning outcomes, they show a level of learning achievement ranging from 71% to 81%. These learning achievement values are highly correlated to the students’ self assessment average achievement values (Figure 10).
Table 2. Exam Results – Quantitative Assessment: Undergraduate University Students

<table>
<thead>
<tr>
<th>Exam question</th>
<th>Learning Outcome</th>
<th>Possible grade</th>
<th>Average grade</th>
<th>Standard Deviation</th>
<th>Learning Achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Detection and green time</td>
<td>10</td>
<td>7.52</td>
<td>2.03</td>
<td>72%</td>
</tr>
<tr>
<td>2</td>
<td>Detection and green time</td>
<td>10</td>
<td>6.88</td>
<td>1.66</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Detection and green time</td>
<td>10</td>
<td>7.33</td>
<td>2.11</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Optimal passage time</td>
<td>10</td>
<td>8.12</td>
<td>1.98</td>
<td>81%</td>
</tr>
<tr>
<td>5</td>
<td>Effect of trucks</td>
<td>10</td>
<td>7.14</td>
<td>2.47</td>
<td>71%</td>
</tr>
<tr>
<td>6</td>
<td>Operation in high speed approaches</td>
<td>10</td>
<td>7.54</td>
<td>2.01</td>
<td>75%</td>
</tr>
<tr>
<td>7</td>
<td>Volume density variable extension</td>
<td>10</td>
<td>6.83</td>
<td>1.65</td>
<td>73%</td>
</tr>
<tr>
<td>8</td>
<td>Volume density variable extension</td>
<td>10</td>
<td>7.62</td>
<td>2.18</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Volume density gap reduction</td>
<td>10</td>
<td>6.88</td>
<td>2.66</td>
<td>71%</td>
</tr>
<tr>
<td>10</td>
<td>Volume density gap reduction</td>
<td>10</td>
<td>7.29</td>
<td>1.98</td>
<td></td>
</tr>
</tbody>
</table>

Figure 10. Exam-Based (Actual) and Self-Assessment Learning Outcome
4. CONCLUDING THOUGHTS

This paper reports on the development and assessment of novel traffic engineering education tools that are based on sound educational models that favor laboratory or hands-on type learning. The mobile signal timing training materials (MOST) presented in this paper is a new paradigm in two respects. First, it involves hands-on experience with “real” traffic controllers. This is important because many traffic engineers have had little direct experience with a traffic controller. The hands on experience provided by MOST designed to provide traffic engineering professionals, with a laboratory environment to experiment with different control plans and test different scenarios in the safety of their office where they are not likely to cause any negative impact on the traffic network. Second, the course material has a strong technical foundation based on sound traffic flow concepts, which can be evaluated using a high quality simulation environment. A significant benefit of this approach is learning the interaction between intersection design parameters and traffic flow characteristics.

The assessments that were conducted during the classroom testing indicated that the most dramatic improvements were observed in the group with the highest proportion of signal technicians. Groups with large representation of engineers showed almost as large increase in knowledge as well. When tested in a classroom environment with undergraduate civil engineering students, the course materials showed high teaching efficiency as indicated by exams score and students’ self assessment survey results. This educational tool is still a working progress. However, it has been quantitatively demonstrated that its educational model is an important component in the traffic engineering profession, raising its grade up from D.
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