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Enhancing Transportation Engineering Education with Computer Simulation*

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There is relatively little emphasis on experiential learning as real-world experience in transport studies. It is difficult to apply to classroom learning because the risks and costs of experimenting with transport policies and concepts in the real world are prohibitively high. To counter this, simulation has proved to be capable of compressing time and space with great cost saving. At the University of Hartford, micro-simulation tools have been integrated into transportation engineering undergraduate courses for the first time to see how the traditional traffic engineering learning experience can be enhanced. A simulation learning environment was created to help students learn the principles of simulation and then develop an intuitive understanding of traffic flow theory and advanced control strategies. Students have also worked with two traffic simulation tools, CORSIM and VISSIM, and used them to understand the interactive dynamics among driver behaviors, vehicle characteristics and advanced traffic control management strategies in urban and freeway transport networks. They could also test hypotheses about the effects of various driver behavior, land use, and network decisions on the resulting traffic levels and make decisions on improvements for the future network. As part of the learning experience offered by this course, students applied the skills and knowledge gained from the classroom to a real-life service-learning project. The project was to take the learned traffic model theories and use simulations to evaluate traffic operations along an important urban corridor in Hartford, Connecticut, in terms of the existing, future, and improved future scenarios. The study results were presented and communicated to the local public. It is believed that the technology-enhanced learning activities of the simulation can reduce the emphasis on instructor-led "chalk and talk" by enabling students to explore complex traffic modeling processes in computerized learning environments. The new learning experience also enables students to think critically about transport problems and solutions.

Keywords: simulation; traffic simulation; transportation engineering education; service-learning project

INTRODUCTION

TECHNOLOGICAL INNOVATIONS play an increasingly important role in engineering education as an effective tool for enhancing classroom learning [1]. The authors' experiences in both teaching and studying transportation engineering has led them to realize that computer simulation, one of these innovations, complements traditional transport engineering education methods. Conventional approaches to transport education emphasize rationality and are dominated by analytical training, and tend to pay less attention to experience, context and intuition [2]. The reason that there is less emphasis on experiential learning lies in the fact that real-world experience in transport study is difficult to apply to classroom learning, because the risks and costs of experimenting with transport policies and concepts in the real world are prohibitively high. To counter this, simulation has shown that it is capable of compressing time and space with a large cost saving benefit. In addition, the importance of using simulation in today's classroom has been recognized for different subject areas. Research [3–6] has shown that simulations are engaging and allow learners to internalize knowledge by applying new skills in a risk-free environment. This can dramatically increase the motivation and knowledge retention rates and provide a high return on learning efforts.

In the field of transportation and traffic engineering, it is very common for students to have difficulty with developing a deep and intuitive understanding of transportation network flow theory and advanced traffic control strategies. The Department of Civil Engineering at the University of Hartford offers a few transportation-related courses, such as senior level Transportation Engineering I (CE 452) and Transportation Engineering II (CE 453), as professional electives

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for both seniors and graduate students. The curricula of these courses devote a considerable amount of time to developing an understanding by the students of fundamentals in highway design, traffic flow theory and traffic control. Thus, in the recently developed transportation engineering course, computer micro-simulation tools are applied to provide an interactive learning environment and interest students in experiments and knowledge construction. The course covers an entire semester and is divided into two stages. During the first half of the semester, a simulation learning environment is created for students to learn traffic model theory and control methods, while in the second stage, the students work on a real-life project using traffic simulation skills. To facilitate this teaching, Web-based course materials are also posted on our Blackboard site for use by the students. The idea behind this teaching structure is to seek how the traditional traffic engineering learning experience can be enhanced through using both simulation and a real-life engineering project. It is expected that this integration will enable students to learn by simulating, the next best thing to learning by doing, which is considered to be a practical approach in fields such as transport that involve a variety of drivers, vehicles and control decisions at any time. This will enable the students to think critically about transport problems and solutions and will produce graduates who understand the theory behind their engineering decisions.

In addition, integrating simulation into teaching promotes active learning and provides the opportunities for students to practice judgment and problem-solving skills. It can diversify an instructor's range of teaching strategies, and accommodate students' different learning styles, therefore enhancing teaching effectiveness.

SIMULATION LEARNING ENVIRONMENT

The simulation learning environment stage comprises two tasks: to teach the simulation principles and theory, and to engage the students in simulation to enable them to understand various traffic flow and control models. The class began with an introduction to traffic simulation and its definition. Traffic simulation models use numerical techniques on a digital computer to create a description of how traffic behaves over extended periods of time for a given transport facility or system [7]. A series of lectures was given in conjunction with the learning-by-doing teaching strategy. Prior to learning the developed traffic simulation tools, students were given an open-ended exercise on building a simple simulation environment for traffic interactions at an unsignaled intersection. Students were grouped into twos and given a week for this assignment. A Microsoft Excel spreadsheet was used to model how queued vehicles on a minor approach to a main road seek gaps in the traffic stream to determine their actions–either wait for another gap, or safely pass through the intersection. Students were also required to consider stochastic driver and vehicle behavior. The simulation environment created by each team varied, depending on the logic they used to design and constructed the simulation. Figure 1 shows an example. With the input of speed, headway and other parameters, minor street vehicle locations and actions are tracked. Arrivals of traffic are modeled as uniform

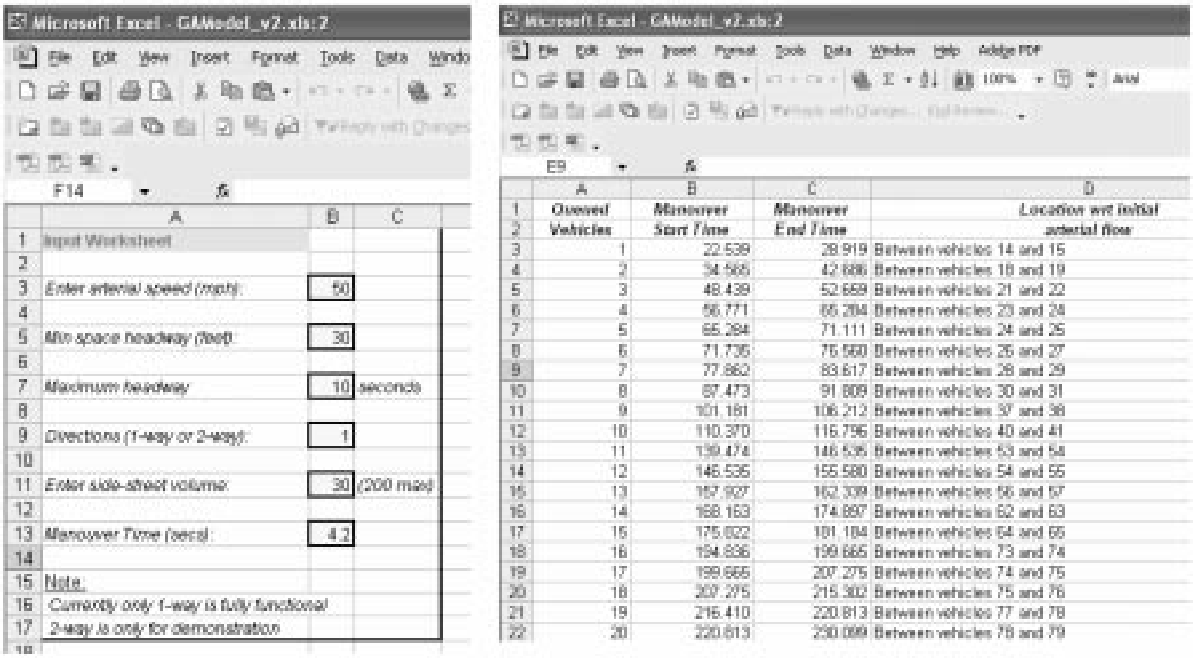

Fig. 1. Building a simulation model using a spreadsheet.

distribution functions. This exercise was designed to help students to understand the principle of traffic simulation, where simulation predicts the performance by stepping through time and across space, tracking events as the system state changes. In addition, it also illustrates the basics of building a simulation model that uses a computer to represent and replicate various transportation facilities, control devices, vehicle movements and driver behavior in real life, no matter whether the simulation environment was built using a commercial software package or by simple spreadsheets.

Secondly, various traffic flow models, such as car following and gap acceptance models were introduced to students after they had grasped the simulation principle. Those models help students to understand simulation calibration and the validation process by which they can confirm that the model does in fact provide a reasonable approximation of reality. In this task, students focused on getting familiar with two microscopic and stochastic traffic simulation models: CORSIM [8], developed by the Federal Highway Administration (FHWA), and VISSIM [9], created by PTV in Germany. Both models are capable of analyzing the traffic operations of a full range of functionally classified roadways including freeways, surface streets and basic transit systems. However, they differ in car following, lane change and other traffic models, which fundamentally determines their applicability. In addition, the two models have different network representations: CORSIM uses links and nodes, while VISSIM employs links and connects to allow more flexibility. Nevertheless, both models served the class objective, and students used them to test hypotheses about the effects of various driver behavior decisions on the resulting transportation network performance. Students have worked on the simulation by modifying various parameters, studying the traffic–density–speed relationship, and visualizing traffic flow performance. Figure 2 presents an example in which students can manipulate traffic data such as signal timing, stop signs, parking spaces and locations, drive lanes, vehicle acceleration or deceleration rates, drivers' aggression, etc., to test design alternatives and hypotheses, and examine traffic flows. This participatory simulation allowed students to understand better the interactive dynamics among driver behavior, vehicle characteristics and advanced traffic control management strategies in urban and freeway transportation networks.

Finally, students also learned how to choose the appropriate simulation tools in terms of applications by examining the characteristics, functions and flexibilities of each candidate model with respect to their potential uses for specific applications. For this, students practiced with various signal traffic control strategies, including pre-timed, actuated and semi-actuated controls. Students were also able to model a transport network that involved different types of facilities, such as freeways, urban arterials, interchange connections, as well as control devices, such as variable message signs, signals and sign controls, etc.

In summary, by integrating simulation into learning about these traffic models, the simulation becomes a means for students to transfer the theory into some sort of practical experience that they can directly appreciate.

COMMUNITY-BASED SERVICE LEARNING PROJECT

Based on their knowledge of the theory, students worked on a real-life project using simulation to model an existing small transport network in the Hartford area and to propose alternatives that could improve it. With the sponsorship of a local consulting company (Urban Engineers, Inc.), an

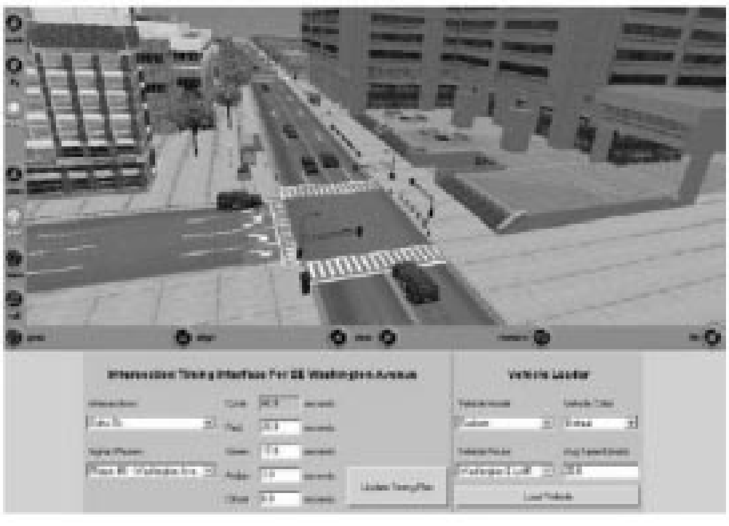

Fig. 2. An example of a simulation learning environment.

Fig. 3. Area of study.

ongoing Route 44 traffic improvement project was selected for the project.

Route 44 is an important corridor connecting Avon, West Hartford, and Hartford in Connecticut. The Hartford and West Hartford area of the Route 44, namely Albany Avenue, serving as a traffic collector for I-91 and I-84, has recurring congestion problems. In particular, the areas around the intersection of Bloomfield Avenue (Route 189), Prospect Avenue, and Main Street (Route 218) with Albany Avenue often experience large delays and queue spillback due to the heavy work-related traffic volume in rush hours. Other problems on Route 44 include a high accident rate, speeding on residential side streets and insufficient parking. With its close proximity to the University of Hartford campus and the Upper Albany commercial area, there are challenges in developing effective traffic control plans for relieving congestions on Albany Avenue. Therefore, the primary goal of the project was to study the existing traffic conditions and generate new signal timings to improve traffic flow and safety in the area, as well as to evaluate the impacts of the proposed improvements. An additional goal of this study was to select an appropriate analysis framework, including comparing the simulation programs that can potentially be used in such a study. As shown in Fig. 3, a significant portion of Albany Avenue that included nine signalized and unsignalized intersections was selected as study area for the analysis.

LEARNING EXPERIENCE THROUGH SIMULATION AND PROJECT

The project is divided into several steps, which consist of data collection, simulation of the existing condition, the design of new signal timing, and the simulation evaluation of the future condition, considering the proposed improvements. Students worked together as teams to complete the task requirements for each step. During data collection, students assembled the given traffic data, including signal plans and turning movement counts for the existing field conditions. Students selected an a.m. peak hour on a weekday to count turning volume at several highly congested intersections for data validation purpose. Traffic, including both vehicles and pedestrians, was recorded in 15 minutes intervals between 8 and 10 a.m. for each turning movement of each approach. Lastly, students summarized geometric, traffic and control conditions for the study area and presented the information professionally. A quantitative assessment of a selected performance measure—travel time for the study area— was collected. This performance measure was used to calibrate and model existing traffic operation conditions. Students also observed other traffic conditions such as pedestrians crossing, mid-block crossing, adjacent stopped-controlled intersections, public transport, etc.

After all the data had been assembled, the students analyzed the traffic operations of the transport network under three scenarios. Scenario one is the existing condition, where students used CORSIM or VISSIM to simulate the network traffic performance, as shown in Fig. 4, and calibrate it based on the field measured travel time. The calibration, the most important and most difficult task in developing a simulation model, is the process of quantifying model parameters using real-world data in the model logic so that the model can realistically represent the traffic environment being analyzed. Based on the learned knowledge on traffic flow models, the students worked on adjusting the parameters of the models that describe vehicles, drivers and traffic model (i.e., car-following, lane-change) characteristics. Rather than accepting these default values, the calibration process adjusts the model by quantifying these default values with site-specific data (travel time) as well as is practical. After the calibration, students should have a better understanding of these traffic models and the calibrated network should output results close to those of the real world. After running the simulation, the students also presented the results and highlighted the intersections or movements that had long delays or queues and other locations that required special attention. Figure 5 shows that the eastbound side of the intersection of Route 44 and Blue Hills has long delays and queues. The second scenario is the future scenario, with the existing traffic volume projected to the year 2010 with a 1.5% increase. Based on the simulation results, the students also identified some critical intersections, using the knowledge of signal control and optimization that they had gained in previous semesters, and re-timed those critical intersection signal controls. The aim was to improve the travel flow by synchronizing signal controls along the arterial road and to reduce stops. In scenario three, the students also analyzed the future scenarios by considering those optimized traffic signal controls, and some proposed improvements, such as the addition of two new signals along Route 44, the realignment of Route 187 to the west to oppose Milford Street (Fig. 6) and general changes to lane configurations, including the introduction of protected left turn lanes and protected parking lanes. The effects of these future conditions are evaluated in the simulation environment.

In all three scenarios studies, because both CORSIM and VISSIM are stochastic models in results analysis, students ran the simulation as many times as necessary depending on their statistical sample size estimation, using different random number seeds, and provided a summary of the appropriate results (i e., appropriate performance measures) at each intersection for each run as well as a histogram of the results. Figure 7 presents comparisons of the travel time and delay time of the entire network for the three scenarios. The chart clearly shows that the future scenario increases travel time and vehicle delay if no improvements are made, but the signal re-timing and some possible geometric changes would improve traffic operations along the arterial. An analysis of each intersection was also conducted by the students. Figure 8 describes an example of the intersection of Route 44 and Blue Hills for the three scenarios. Vehicle delay (seconds per vehicle) is presented for each approach. It is obvious that not every approach has the same facility to improve delay. In this case, in order to maintain progression quality along the eastbound and westbound side of the main street, the southbound traffic has to wait longer to be discharged. Based on the analysis of each individual intersection, some recommendations were adjusted by the students. The study recommended that various safety improvements be completed within the corridor. These improvements include intersection improvements, intersection realignments, general changes to lane configurations including introduc-

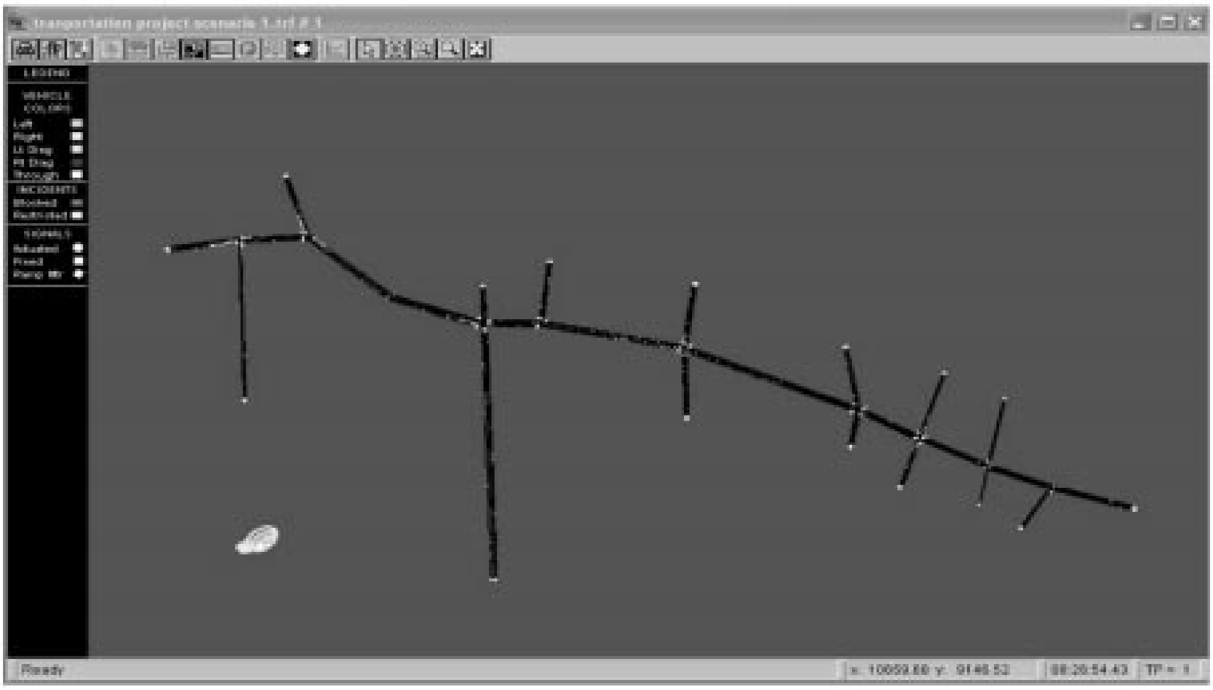

Fig. 4. Simulation representation of existing conditions for overall network.

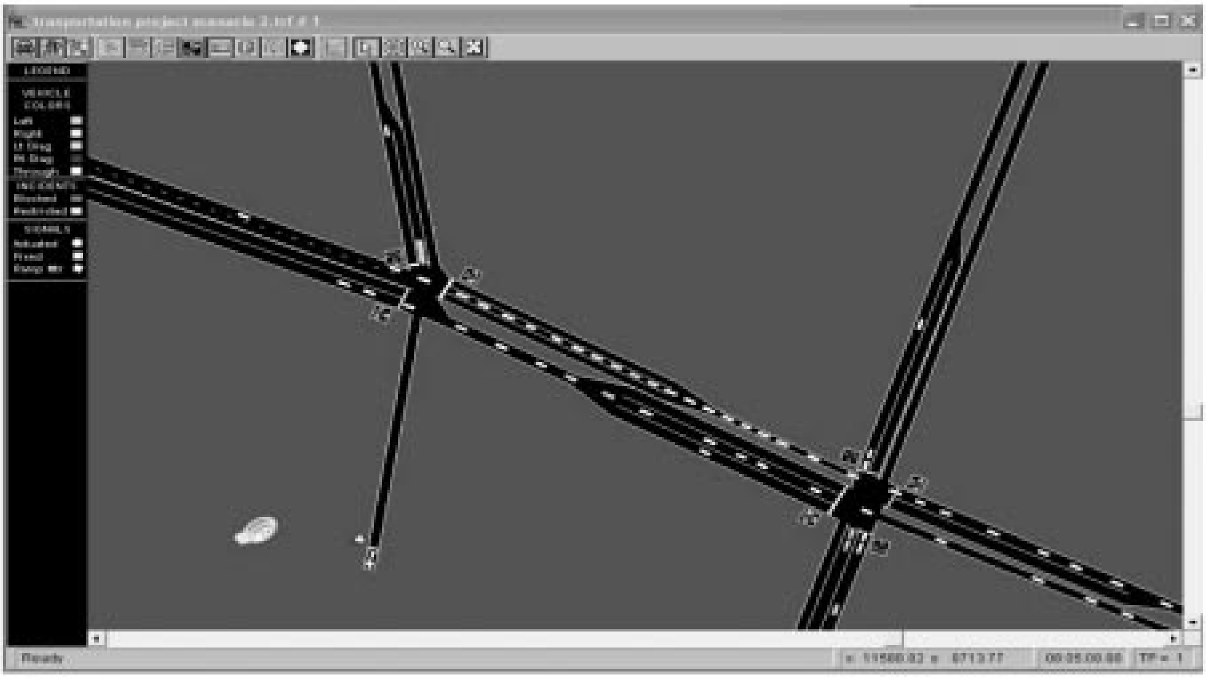

Fig. 5. An example of simulation of one critical intersection (Route 44 and Blue Hills).

Fig. 6. Proposed improvements for the intersection of Route 44 and Blue Hills.

tion of protected left turn lanes, protected parking lanes, roadway widening and bus turnouts. The study also proposed the development of streetscape improvements on Albany Avenue to enhance the corridor as a retail center.

In summary, students gained hands-on learning experience through a project involving simulation models and associated traffic flow and control theories. At this stage, the students should be able to apply simulation to the preliminarily planning, design and operational analysis of transport systems, select an appropriate simulation model

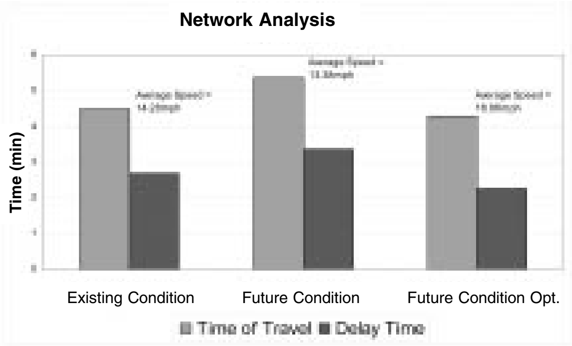

Fig. 7. A comparison of simulation results of three scenarios for the overall network.

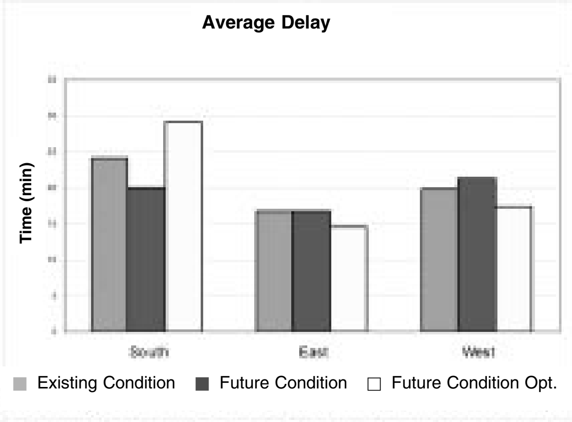

Fig. 8. A comparison of simulation results of three scenarios for the intersection of Route 44 and Blue Hills.

for a particular application, and test hypotheses about the effects of various driver behavioral, land use, economic, and network decisions on resulting traffic levels and future network investment and market location decisions.

ASSESSMENT AND DISSEMINATION

The primary assessment method to determine whether the proposed teaching strategy is feasible and useful is through evaluation. Students were surveyed about the qualities of the model: things that worked well and those that did not, and suggestions for future changes. The immediate feedback from the students was generally positive. More interesting thoughts come from several students who have graduated. They shared their experience with this course as below.

- I thought the class was very helpful and I could apply what I learned to my work. . . .I think that it was great that the class got to work on a real project and present it to members of Upper Albany Main Street, ConnDOT, and CRCOG. [ConnDOT–Connecticut Department of Transportation, CROCG—Capitol Region Council of Governments]
- I liked the exercise with using Excel to build a gap acceptance model for stop sign intersection. This makes other simulation exercises more approachable.
- For the overall class, . . . I think it is a great class to have. The experience with CORSIM and VISSIM definitely helped me so far at work. I'm being put in charge of doing some of the synchro work in my department because it is very similar to CORSIM and they think I'm good at it.
- Pertaining to the course, I thought it went well. It gave a good overview of many simulation programs that will be helpful in the future. The only suggestion I might give is focusing in on CORSIM and VISSIM a little more and maybe getting more of the manuals for troubleshooting. These seemed to be the most useful. I also liked the final project and how it brought everything together. I also liked the PowerPoints and how they explained the programs.

At the end of the semester, the students also presented their work to a community public meeting organized by the Upper Albany Main Office, which directs the community's planning and development. The engineers from ConnDOT and other agencies also attended the meeting. The presentation included the group's methodology, results, conclusions and recommendations. Each group's presentation was approximately 20 minutes. The students' presentation were evaluated based on soundness of recommendations, quality of visual aids, coverage of the subject matter, preparation and organization, ability of effectively address questions, overall presentation style, and professionalism. The public gave encouraging comments. The following is part of the email from the Executive director of the Main Office.

> On behalf of the Upper Albany Main Street Design Committee we wanted to take this opportunity to thank you and your students for a very engaging and informative presentation. I know that the members of our Design Committee were delighted with the simulation of the traffic patterns created by your students for Albany Avenue based on the Route 44 Safety Improvement Project. This was truly evidenced by the number of questions asked throughout the presentation. We also want to especially thank xx [names omitted] for their hard work on the presentation and their excellent presentation skills.

In addition, this project has produced some useful products including multimedia PowerPoint lecture material, the applicability of simulation tools and students' experience throughout this interactive learning environment, etc. These products will also be disseminated to colleagues in Civil Engineering, the College of Engineering, Technology, and Architecture (CETA), and the University community through campus seminars and to professionals through some presentations. The results from the study have also been communicated to the ConnDOT.

CONCLUSIONS AND RECOMMENDATIONS

This new teaching experience led to some results: (1) A technology-enhanced simulation learning environment in senior level transport engineering courses; (2) A real-life project for senior students prior to their professional career; and (3) Multimedia and computer-assisted teaching facilitated with Blackboard. All civil engineering students will be impacted throughout their undergraduate experience at the University of Hartford by this new teaching of integrating simulation and service-learning into transport engineering education. The computer traffic simulation tools help the students to gain insight and understanding through a hands-on learning process of hypothesis and alternative testing of traffic flow theory, and advanced urban and freeway traffic control strategies. These simulation technology-enhanced learning activities can reduce the emphasis on instructor-led ''chalk and talk'' by enabling students to explore complex traffic modeling processes in computerized learning environments. Through simulation, experiential learning can be facilitated and encouraged. The students also had opportunities to evaluate, synthesize, and analyze their own experiences. The community-based service learning project also allows students to apply their skills and knowledge learned from classrooms to real-life projects. This can particularly enrich their learning experience and it also strengthens communities.

Some recommendations have also been derived from this experience: it is planned to expand the use of simulation to teach more topics such as the way in which human factors, car following theory, and flows at freeways affect transportation network operations, therefore engaging students in a more exciting way. A more quantitative assessment is necessary in order to evaluate how well the simulation met its educational objectives and whether they are worthwhile.

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