# AC 2007-261: INTEGRATING SIMULATION INTO TRANSPORTATION ENGINEERING EDUCATION

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# Integrating Simulation into Transportation Engineering Education

## Abstract

The reason for less emphasis on experiential learning lies in the fact that real-world experience in transportation is difficult to apply to classroom learning, because the risks and costs of experimenting with transportation policies and concepts in the real world are prohibitively high. Under this circumstance, simulation has shown its capability to compress time and space with great cost saving benefits. At the University of Hartford, micro-simulation tools have been integrated into transportation engineering undergraduate education for the first time to see how 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 also have 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 transportation networks, and test hypotheses about the effects of various driver behavioral, land use, and network decision on resulting traffic levels and future network improvement decisions. As part of the learning experience offered by this course, students have also applied their skills and knowledge gained from classrooms into a real-life service-learning project. The project was to use the learned theory in traffic models and employ simulation to evaluate traffic operations along an important urban corridor in Hartford in terms of existing, future, and future with improvement scenarios. The study results were presented and communicated to the community public. It is believed that the simulation technology-enhanced learning activities can de-emphasize instructor-led "chalk and talk" by enabling students to explore complex traffic modeling processes in computerized learning environments, and the new learning experience enables students to think critically about transportation problems and solutions.

## 1. Introduction

Technology innovations play an increasingly important role in engineering education as an effective tool for enhancing classroom learning. My experience in both teaching and studying transportation engineering has me realize that computer simulation, one of these innovations, complements traditional transportation engineering education methods. Conventional approaches to transportation education emphasize rationality and are dominated by analytical training, which tends to deemphasize sensitivity to experience, context, and intuition [1]. The reason for less emphasis on experiential learning lies in the fact that real-world experience in transportation is difficult to apply to classroom learning, because the risks and costs of experimenting with transportation policies and concepts in the real world are prohibitively high. Under this circumstance, simulation has shown its capability to compress time and space with great cost saving benefit. In addition, the importance of using simulation in today's classroom has been recognized in different subjects. Research[2,3] has shown that simulations are engaging and allow learners to internalize knowledge by applying new skills in a risk-free environment, which can dramatically increase motivation and retention rates and provide a high return on learning efforts.

In the field of transportation and traffic engineering, it is very common that students have a difficult time 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 elective for both seniors and graduate students. The curricula of these courses devote a considerable amount of time to students, developing an understanding of fundamentals in highway design, traffic flow theory and traffic control. Thus, in my recent developed transportation engineering course, computer micro-simulation tools are applied to provide a interactive learning environment and engage students' motivation in experiments and knowledge construction. The course, covering an entire semester, is divided into two stages. The first half of the semester is to create a simulation learning environment for students to learn traffic model theory and control methods, while during 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 implemented on our Blackboard site for use by students. The idea behind this teaching structure is to see how the traditional traffic engineering learning experience can be enhanced through cooperative 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, and the only practical approach in a field such as transportation that involves various drivers, vehicles and control decisions at any time. It will thus enable them to critically think about transportation problems and solutions and will produce students who understand the theory to support their engineering decisions.

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

## 2. Simulation Learning Environment

The simulation learning environment stage comprises two tasks: teach the simulation principles and theory, and engage students in participatory simulation for understanding various traffic flow and control models. The class began with an introduction of 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 transportation facility or system [4]. 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 unsignalized intersection. Students were grouped two in a team and given a week for this assignment. A Microsoft Excel spreadsheet was used to model how queued vehicles at a minor approach seek gaps among traffic streams at a main approach 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 how they logically designed 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 in uniform distribution functions. This exercise was designed to help students understand the principle of traffic simulation, where simulation predicts performance by stepping through time and across space, tracking events as the system state unfolds. In addition, it also illustrates the basics of building a simulation model which is to use a computer to represent and replicate various transportation facilities, control devices, vehicle movements and driver behavior in reality, no matter whether the simulation environment was built by a commercially 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 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, developed by the Federal Highway Administration (FHWA), and VISSIM, created by PTV in Germany. Both models are capable of analyzing 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. Additionally, two models have different network representations: CORSIM uses link and node while VISSIM employs links and connects to allow more flexibility. Nevertheless, both models have served the class objective, and students used them to test hypotheses about the effects of various driver behavioral decisions on 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 sign, parking spaces and locations, drive lanes, vehicle acceleration or deceleration rates, drivers aggression, etc., to test different design alternatives and hypothesis, and examine traffic flows. This participatory simulation allowed students to better understand the interactive dynamics among driver behaviors, vehicle characteristics and advanced traffic control management strategies in urban and freeway transportation networks.

Finally, students also learned how to choose an appropriate simulation tools in terms of applications by examining the characteristics, functions and flexibilities of each candidate model with respect to the potential of being used to for a specific application. For this topic, students have practiced on various signal traffic control strategies, including pre-timed, actuated and semi-actuated. Students were also able to model a transportation network involving different type of facilities, such as freeway, urban arterials, interchange connections, as well as control devices, such as variable message signs, signals and sign controls, etc.

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

## 3. Community-Based Service Learning Project

Based on what they have learned in theory, students conducted a real-life project using the simulation to model an existing small transportation network in the Hartford area and propose improvement alternatives. With the sponsorship of a local consulting company (Urban Engineers, Inc.), an ongoing Route 44 traffic improvement project was selected for students.

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, usually has recurring congestion problems. Particularly 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 heavy work-related traffic volume in the 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 is to study the existing traffic conditions and generate new signal timings to improve traffic flow and safety in the area as well as evaluate the impacts of the proposed improvements. An additional goal of this study is to select an appropriate analysis framework, including comparing the simulation programs that can potentially be used in such a study. As shown in Figure 3, a significant portion of Albany Avenue including nine signalized and unsignalized intersections is selected as study area for the analysis.

## 4. Learning Experience through Simulation and Project

The project is divided into several steps which consist of data collection, simulation of existing condition, the design of new signal timing, and the simulation evaluation of future condition by considering proposed improvements. Students have worked together as teams (3 groups with 2 students each) 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 existing field conditions. Students selected an AM peak hour in a weekday to count turning volume at several highly congested intersections for data validation purpose. Figure 4 shows an example of turning traffic counts for an intersection collected by students using traffic counters. Traffic including both vehicles and pedestrians was recorded in 15 minutes segments between 8 and 10am for each turning movement of each approach. Last, students summarized geometric, traffic and control conditions for the study area and professionally presented the information. 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 should also observe other traffic conditions such as pedestrians crossing, mid-block crossing, adjacent stopped-controlled intersections, public transportation, etc.

After all data were assembled, students analyzed traffic operations of the transportation network in three scenarios. Scenario one is existing condition where students used CORSIM or VISSIM to simulate the network traffic performance, as shown in Figure 5, and calibrated it based on the field measured travel time. The calibration, the most important but 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, students worked on adjusting the parameters of the models which 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) to the extent practical. After the calibration, students should have a better understanding of these traffic models and the calibrated network should output results close to the real space world. After running the simulation, students also presented the results and highlighted the intersections or movements with high delay or queues and other locations which require special attentions. Figure 6 shows that the Eastbound side of the intersection of Route 44 and Blue Hills has high delay and queues.

Scenario two is future scenario, where the existing traffic volume will be projected to a future year of 2010 with a rate of 1.5% increase. Based on simulation results, students also identified some critical intersections, used the knowledge that they learned in previous semesters about signal control and optimization, and re-timed those critical intersection signal controls. The purpose is to improve the travel progression by synchronizing signal control along the arterial and reduce stops.

In scenario three, students also analyzed future scenarios by considering those optimized traffic signal controls, and some proposed improvements, such as adding two new signals along Route 44; realignment of Route 187 to the west to oppose Milford Street (Figure 7), 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 according to 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 histogram of the results. Figure 8 presents travel time and delay time comparisons of the entire network for the three scenarios. The chart clearly shows that the future scenario increases travel time and vehicle delay if there is no improvement done, 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 9 describes an example of the intersection of Route 44 and Blue Hills. Vehicle delay (sec per vehicle) is presented for each approach. It is obvious that not every approach has the same tendency 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 time 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 introduction 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 have gained hands-on learning experience through a project involving simulation models and associated traffic flow and control theories. At this stage, students should be able to apply simulation to the preliminarily planning, design and operational analysis of transportation systems, select an appropriate simulation model for various applications, 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.

## 5. Assessment and Dissemination

The primary assessment method to determine whether the proposed teaching strategy is feasible and useful is through student evaluation. Students were surveyed about qualities of the model, things that work well and do not, and suggestions for future changes. The immediate feedback from 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" (Note: 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 Im 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, 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 styles 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 materials, 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.

## 6. Conclusions and Recommendations

This new teaching experience led to some results: 1) A technology-enhanced simulation learning environment in senior level transportation 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 transportation engineering education. The computer traffic simulation tools facilitate students' deriving insight and understanding through a hands-on learning process of hypothesis and alternative testing of traffic flow theory, advanced urban and freeway traffic control strategies. These simulation technology-enhanced learning activities can de-emphasize 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 into the real-life projects. Those particularly can enrich their learning experience and also strengthen 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 how human factors, car following theory, and flows at freeways affect transportation network operations, therefore engaging students in a more exciting manner. A more quantitative assessment is necessary to evaluate how well the simulation met its educational objectives and whether they are worthwhile.

## Acknowledgement

This work was supported in part by the University of Hartford Faculty Center for Learning Development's Technology Innovation Fund.

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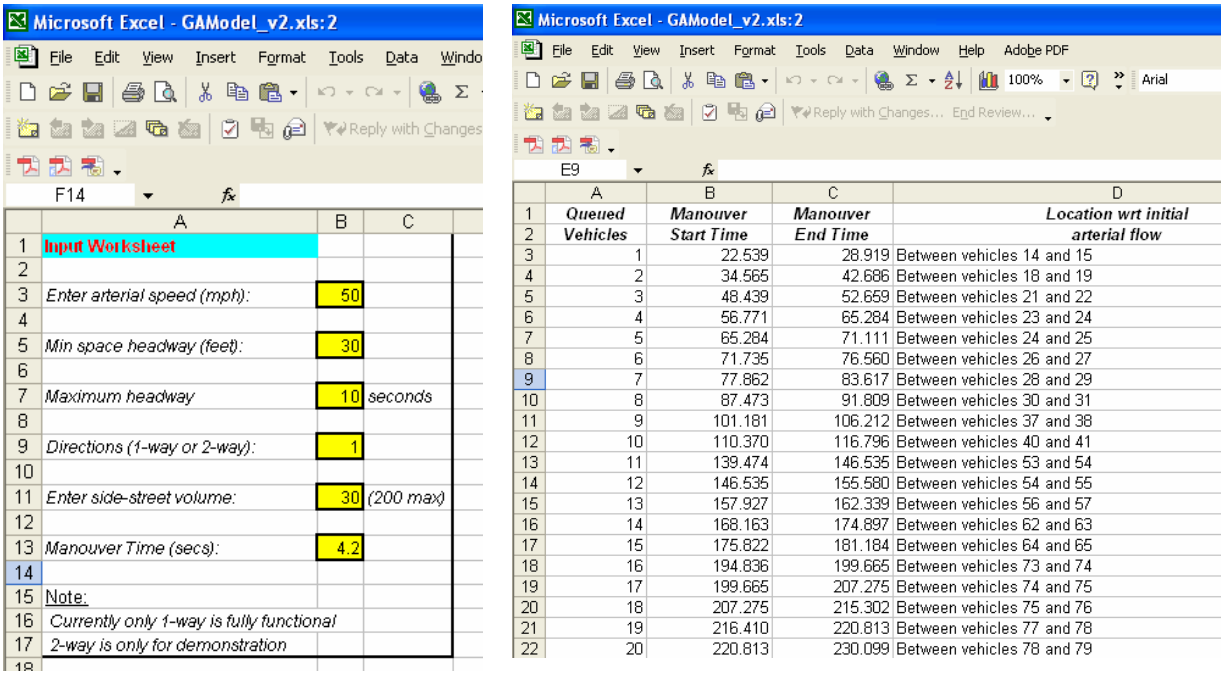

Microsoft Excel - GAModel_v2.xls:2

| | A | B | C |
|---|---|---|---|
| 1 | Input Worksheet | | |
| 2 | | | |
| 3 | Enter arterial speed (mph): | 50 | |
| 4 | | | |
| 5 | Min space headway (feet): | 30 | |
| 6 | | | |
| 7 | Maximum headway | 10 | seconds |
| 8 | | | |
| 9 | Directions (1-way or 2-way): | 1 | |
| 10 | | | |
| 11 | Enter side-street volume: | 30 | (200 max) |
| 12 | | | |
| 13 | Manouver Time (secs): | 4.2 | |
| 14 | | | |
| 15 | Note: | | |
| 16 | Currently only 1-way is fully functional | | |
| 17 | 2-way is only for demonstration | | |

Microsoft Excel - GAModel_v2.xls:2

| | A | B | C | D |
|---|---|---|---|---|
| 1 | Queued | Manouver | Manouver | Location wrt initial |
| 2 | Vehicles | Start Time | End Time | arterial flow |
| 3 | 1 | 22.539 | 28.919 | Between vehicles 14 and 15 |
| 4 | 2 | 34.565 | 42.686 | Between vehicles 18 and 19 |
| 5 | 3 | 48.439 | 52.659 | Between vehicles 21 and 22 |
| 6 | 4 | 56.771 | 65.284 | Between vehicles 23 and 24 |
| 7 | 5 | 65.284 | 71.111 | Between vehicles 24 and 25 |
| 8 | 6 | 71.735 | 76.560 | Between vehicles 26 and 27 |
| 9 | 7 | 77.862 | 83.617 | Between vehicles 28 and 29 |
| 10 | 8 | 87.473 | 91.809 | Between vehicles 30 and 31 |
| 11 | 9 | 101.181 | 106.212 | Between vehicles 37 and 38 |
| 12 | 10 | 110.370 | 116.796 | Between vehicles 40 and 41 |
| 13 | 11 | 139.474 | 146.535 | Between vehicles 53 and 54 |
| 14 | 12 | 146.535 | 155.580 | Between vehicles 54 and 55 |
| 15 | 13 | 157.927 | 162.339 | Between vehicles 56 and 57 |
| 16 | 14 | 168.163 | 174.897 | Between vehicles 62 and 63 |
| 17 | 15 | 175.822 | 181.184 | Between vehicles 64 and 65 |
| 18 | 16 | 194.836 | 199.665 | Between vehicles 73 and 74 |
| 19 | 17 | 199.665 | 207.275 | Between vehicles 74 and 75 |
| 20 | 18 | 207.275 | 215.302 | Between vehicles 75 and 76 |
| 21 | 19 | 216.410 | 220.813 | Between vehicles 77 and 78 |
| 22 | 20 | 220.813 | 230.099 | Between vehicles 78 and 79 |

**FIGURE 1 Building a Simulation Model Using a Spreadsheet**


**FIGURE 2 An Example of a Simulation Learning Environment**

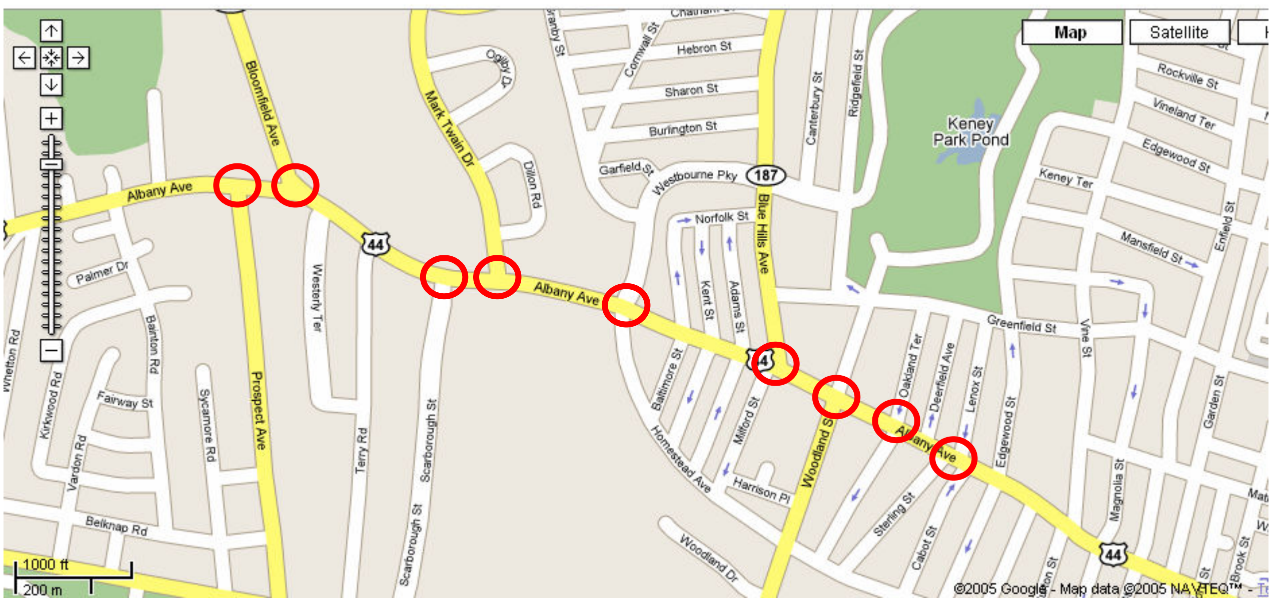


**FIGURE 3 Study Area (*http:// www.google.com/maps*)**
(Note: each red circle represents signal location.)

Urban Engineers, Inc.
1010 Wethersfield Avenue
Hartford CT 06114

Intersection: Albany at Lennox/Cabot
Date: April 12, 2006
Weather: Sunny
Counted by: Chris J

File Name : LenCablot AM
Site Code : 00000006
Start Date : 4/12/2006
Page No : 1

Groups Printed- Cars - Trucks and Buses

| | Lennox St From North | | | | | Albany Ave From East | | | | | Cabot St From South | | | | | Albany Ave From West | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Time | Right | Thru | Left | Peds | App. Total | Right | Thru | Left | Peds | App. Total | Right | Thru | Left | Peds | App. Total | Right | Thru | Left | Peds | App. Total | Int. Total |
| Factor | 1.0 | 1.0 | 1.0 | 1.0 | | 1.0 | 1.0 | 1.0 | 1.0 | | 1.0 | 1.0 | 1.0 | 1.0 | | 1.0 | 1.0 | 1.0 | 1.0 | | |
| 07:00 AM | 8 | 0 | 6 | 3 | 17 | 0 | 52 | 0 | 9 | 61 | 13 | 0 | 5 | 5 | 23 | 0 | 111 | 0 | 8 | 119 | 220 |
| 07:15 AM | 16 | 0 | 10 | 6 | 32 | 0 | 94 | 0 | 13 | 107 | 21 | 0 | 2 | 1 | 24 | 0 | 153 | 0 | 9 | 162 | 325 |
| 07:30 AM | 11 | 0 | 22 | 2 | 35 | 0 | 75 | 0 | 23 | 98 | 16 | 0 | 5 | 4 | 25 | 0 | 186 | 0 | 1 | 187 | 345 |
| 07:45 AM | 16 | 0 | 8 | 6 | 30 | 0 | 90 | 0 | 16 | 106 | 21 | 0 | 13 | 1 | 35 | 0 | 235 | 0 | 6 | 241 | 412 |
| Total | 51 | 0 | 46 | 17 | 114 | 0 | 311 | 0 | 61 | 372 | 71 | 0 | 25 | 11 | 107 | 0 | 685 | 0 | 24 | 709 | 1302 |
| 08:00 AM | 15 | 0 | 18 | 1 | 34 | 0 | 87 | 0 | 25 | 112 | 21 | 0 | 5 | 8 | 34 | 0 | 216 | 0 | 8 | 224 | 404 |
| 08:15 AM | 12 | 0 | 15 | 5 | 32 | 0 | 77 | 0 | 6 | 83 | 30 | 0 | 4 | 3 | 37 | 0 | 216 | 0 | 5 | 221 | 373 |
| 08:30 AM | 11 | 0 | 5 | 2 | 18 | 0 | 105 | 0 | 11 | 116 | 28 | 0 | 7 | 0 | 35 | 0 | 182 | 0 | 8 | 190 | 359 |
| 08:45 AM | 8 | 0 | 13 | 2 | 23 | 0 | 91 | 0 | 6 | 97 | 27 | 0 | 7 | 0 | 34 | 0 | 151 | 0 | 6 | 157 | 311 |
| Total | 46 | 0 | 51 | 10 | 107 | 0 | 360 | 0 | 48 | 408 | 106 | 0 | 23 | 11 | 140 | 0 | 765 | 0 | 27 | 792 | 1447 |
| Grand Total | 97 | 0 | 97 | 27 | 221 | 0 | 671 | 0 | 109 | 780 | 177 | 0 | 48 | 22 | 247 | 0 | 1450 | 0 | 51 | 1501 | 2749 |
| Apprch % | 43.9 | 0.0 | 43.9 | 12.2 | | 0.0 | 86.0 | 0.0 | 14.0 | | 71.7 | 0.0 | 19.4 | 8.9 | | 0.0 | 96.6 | 0.0 | 3.4 | | |
| Total % | 3.5 | 0.0 | 3.5 | 1.0 | 8.0 | 0.0 | 24.4 | 0.0 | 4.0 | 28.4 | 6.4 | 0.0 | 1.7 | 0.8 | 9.0 | 0.0 | 52.7 | 0.0 | 1.9 | 54.6 | |

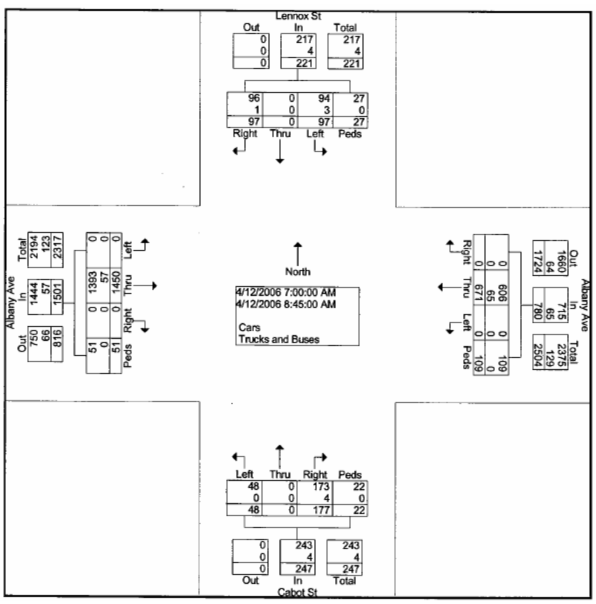


**FIGURE 4 Data Collection by Traffic Counts**

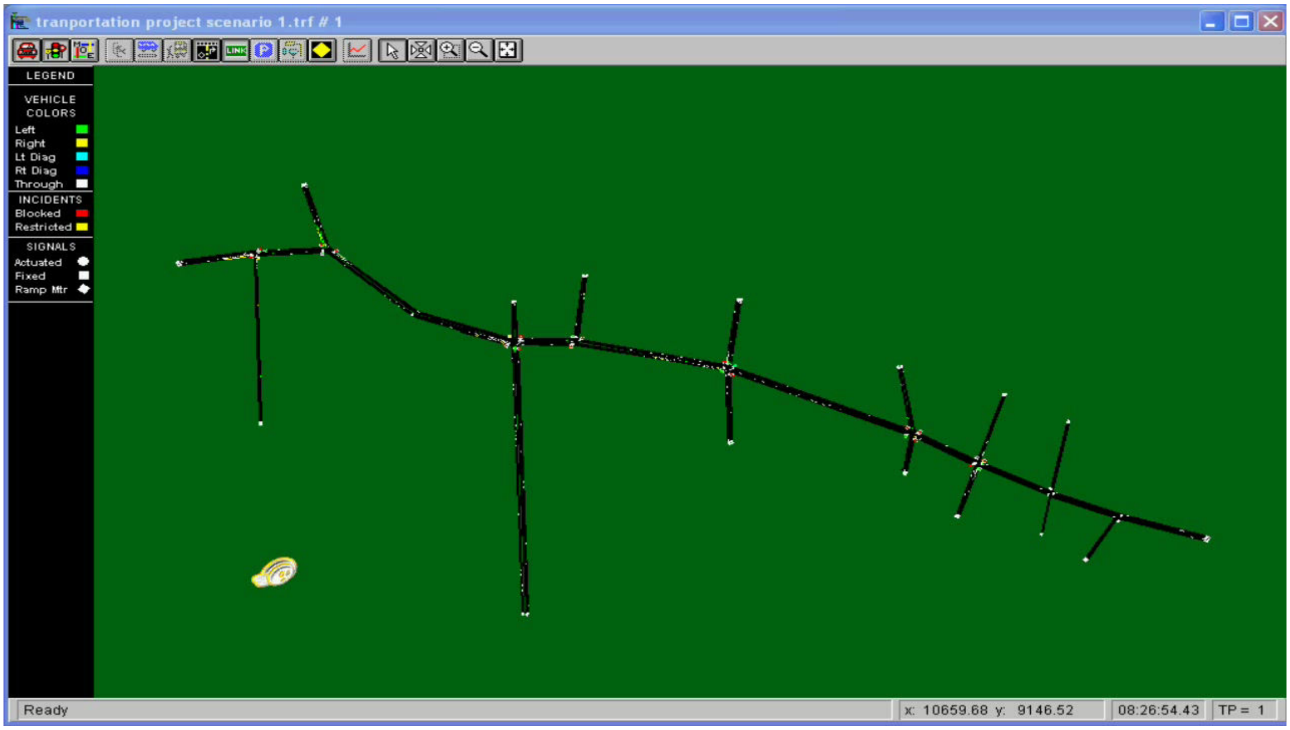


**FIGURE 5 Simulation Representation of Existing Conditions for Overall Network**

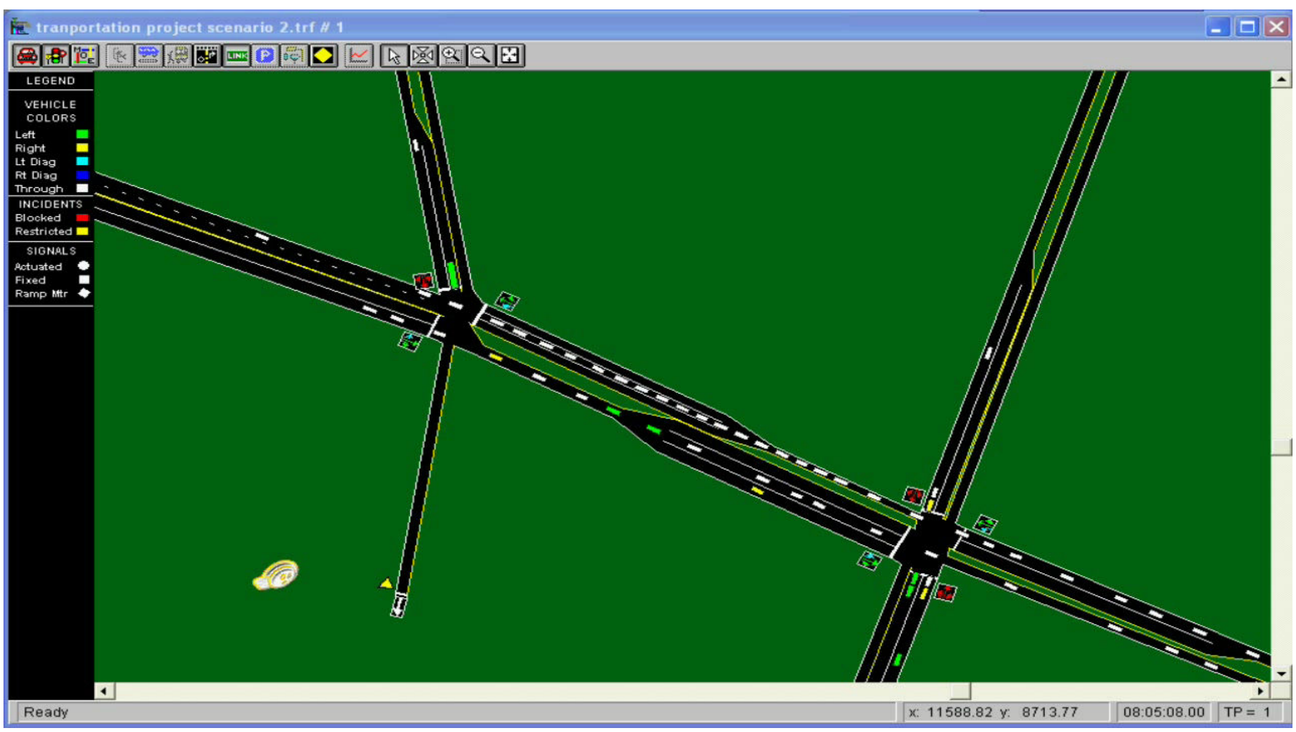

**FIGURE 6 An Example of Simulation of one Critical Intersection (Route 44 & Blue Hills)**


**FIGURE 7 Proposed Improvements for the Intersection of Route 44 & Blue Hills**

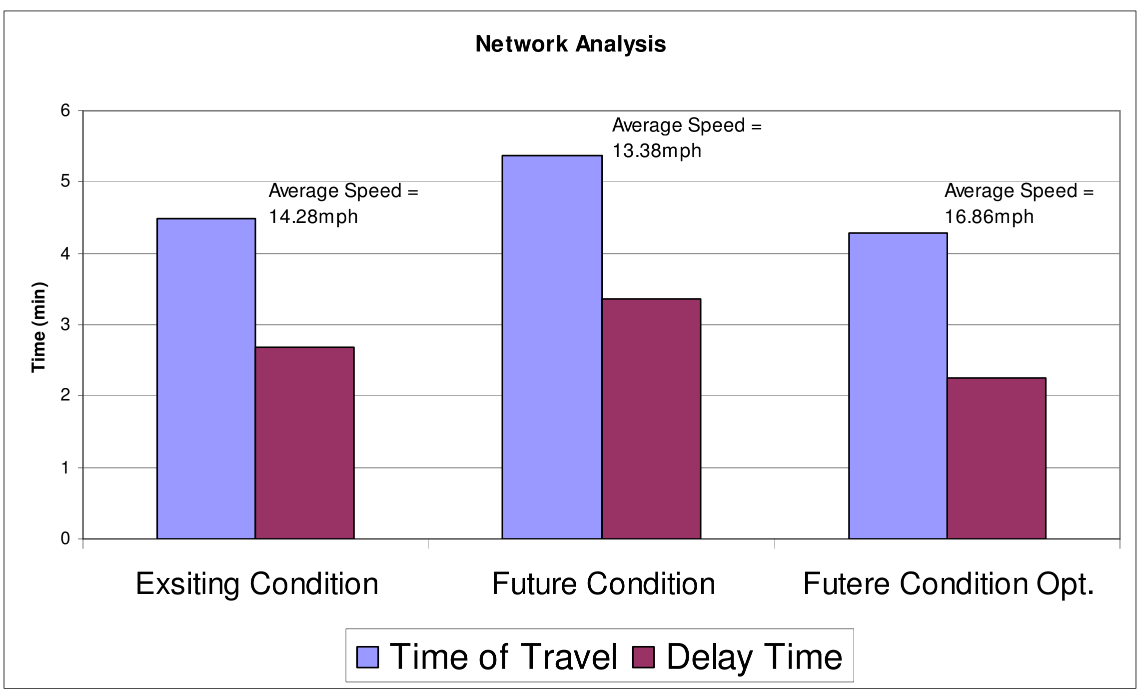

**FIGURE 8 A Comparison on Simulation Results of Three Scenarios for Overall Network**

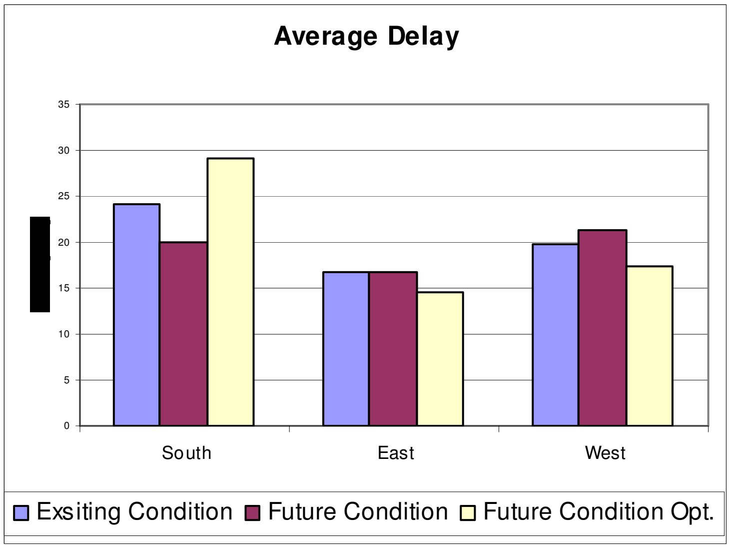


**FIGURE 9 A Comparison of Simulation Results of Three Scenarios for the Intersection of Route 44 & Blue Hills**