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THE IMPORTANCE OF SIMULATION TECHNIQUES IN ITS RESEARCH AND ANALYSIS

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ABSTRACT

Traffic congestion has historically been regarded as a problem confined to major metropolitan areas. Over the years, the traffic problems that existed in densely developed urban areas began creeping into the suburbs as the work force migrated away from the traditional center city work pattern. Modern business operates at a feverish pace and is more mobile in nature, automobile technology advances have allowed more people to drive, and the commuting public has caused traffic congestion problems to appear even in small towns. Simply adding pavement to mitigate the traffic problems is neither adequate nor feasible.

The Intelligent Transportation Systems (ITS) initiative was invoked by congress in 1991 to advance our traffic control systems by fostering development of Advanced Traffic Management Systems (ATMS). These technologies are designed to help move the motoring public more efficiently over the existing transportation system. Computer simulation has proved to be a vital adjunct to traditional traffic engineering analysis methods in fully understanding the dynamics of traffic movement and control operations,. These simulation tools are critical in the development and evaluation of these new ideas, algorithms, and traffic control systems. This paper presents three case studies illustrating the importance and positive impacts of traffic simulation techniques.

1 APPLYING SIMULATION TO REAL WORLD PROBLEMS

Importance: It is not uncommon for a roadway corridor to experience increasing traffic congestion and operational problems, due to rapid growth in traffic volumes associated with major land use development. This increase in traffic volumes, coupled with often short distances between intersections/interchanges, heavy turning movements, numerous on/off ramps or driveway locations, and increased cross street traffic demand, requires the transportation professional to adopt a "systems analysis" approach to properly address traffic congestion. In doing so, the impacts of potential design and traffic control improvements along the roadway corridor can be better evaluated.

Excessive traffic demand along a corridor more often than not results in traffic congestion due to effects of overlapping bottleneck locations. The spillover effect of traffic congestion from one location to another negates the use of conventional traffic engineering measures of effectiveness such as roadway capacity or levels of service analysis techniques. Traditional capacity analysis methods can provide levels of service estimates at a given point in space and time, but these methods do not provide an assessment of the impacts on the rest of the roadway corridor. As a result, the effects of one bottleneck location on another location are not recognized.

The state-of-the-art method for evaluating the effects of overlapping traffic congestion problems is traffic simulation modeling. Computer traffic simulation models are valuable traffic engineering analytical tools. These models have the capability of evaluating detailed traffic performance at interchanges/intersections, along highway/arterials, or even large transportation networks. They provide the most detailed objective operational analysis technique available for evaluating design and traffic control features.

Traffic simulation models play a vital role in allowing the transportation engineer to evaluate complex traffic situations that cannot be analyzed directly with other means. The models afford the opportunity to evaluate traffic control and design strategies without committing expensive, time-consuming resources necessary to implement the alternative strategies in the field. For this reason, the simulation models allow the engineer to analyze many alternatives quickly and avoid the risk, expense and disruption associated with extensive field experimentation.

As described above, the computer simulation models can help the practicing transportation engineer analyze everyday traffic management needs by looking at congestion problems to understand their source. The practitioner can explore alternatives that range from adding lanes or redefining lane usage, to manipulating the traffic control systems by re-timing intersection signals or by defining new turn movements (e.g. protected left turns). But computer simulation can do much more. Existing and new traffic control devices can be integrated with the computer simulation offering a controlled laboratory environment for testing and evaluating the equipment, or developing new strategies that may use existing or new equipment effectively and efficiently. This is a key point as many times it is very difficult to accurately measure the performance of traffic control systems after they have been deployed. Experience has shown that after deploying such systems, actual throughput (in terms of people and goods) may be affected significantly though visual observations may not be obvious.

2 THE CORSIM SIMULATION MODEL

The CORSIM traffic simulation program is a microscopic stochastic model of non-freeway and freeway traffic operations. The model was developed by the Federal Highway Administration (FHWA) and is part of the TRAF family of simulation models. It combines TRAF-NETSIM, a simulation model of non-freeway traffic, and FRESIM, a simulation model of freeway traffic. CORSIM, being microscopic, models each vehicle (automobiles, buses and trucks) as a separate entity on the network. Vehicles are moved every second. The behavior of each vehicle is represented in the model through interaction with its surrounding environment, which includes network geometry, traffic control and the relationship of nearby vehicles. Active traffic control systems such as intersection controllers and ramp-metering devices are also modeled and have an influence on the behavior of vehicles.

The model simulates urban (non-freeway) traffic operations. The goal of this model, as with all TRAF models, is to represent real-world traffic conditions. In the model, as vehicles are moved each second, each variable control device (signal controls) and each event (incidents, parking) are updated every second. Each vehicle's kinetic properties, such as speed, acceleration and deceleration, are determined, as well as its position on the roadway and in relationship to nearby vehicles. The interaction between cars, trucks, and buses is also modeled. Vehicles are moved according to a car-following logic, response to traffic control devices, and response to other demands. Turning movements at intersections in the network are assigned stochastically, as are free-flow speeds, queue discharge headway, and other behavioral attributes, such as driver behavioral characteristics. Pre-timed and actuated signal controls can be explicitly modeled, as well as stop and yield signs. The model also has the ability to model high occupancy vehicle (HOV) lanes and transit operations.

The model also has the ability of simulating most of the prevailing freeway geometric conditions. This includes one to five through-lane mainline freeways, inter-freeway connectors, grade variations, radius of curvature, superelevation on the freeway, lane additions and drops, freeway incidents (including the effects of vehicle driver rubbernecking), and auxiliary lanes to on- and off-ramps. The model includes clock-time and traffic responsive ramp metering, a comprehensive lane-changing logic, and a freeway surveillance system. The model can also bias or restrict trucks to certain lanes, as well as model vehicles' reaction to upcoming geometric changes through the use of warning signs. Differences in driver habits can also be modeled.

The components of CORSIM have been in use in various forms for over 25 years in conducting traditional traffic modeling analyses. It is written in FORTRAN, and currently has several hundred thousand lines of code. It originally operated on mainframe computers, and today it operates on personal computers (PCs) and workstation class computers. In the PC environment it has recently been upgraded to operate under Microsoft Windows 95 on the PC, and operates within a new Windows environment called the Traffic Software Integrated System (TSIS). Integrating CORSIM into TSIS has allowed FHWA to develop more user-friendly interfaces to CORSIM and also extend CORSIM's capabilities to operate with other processes.

CORSIM Input: Currently, the input-data file for CORSIM is an ASCII file. A prototype graphical input processor named ITRAF was developed by Oak Ridge National Laboratory serves as a user interface to the ASCII input file (though traditionalists still enjoy manipulating the ASCII file using an editor).

There are currently several TRAF models, each with a different input data mechanism and different input data set describing many of the same features such as roadways. A companion effort is underway to create a standard "Traffic Software Data Dictionary" and a database to combine the disparate roadway definitions and terms into one cohesive structure to allow the exchange of data between the models and also ease the burden of generating the input data sets. This will replace the ASCII input file CORSIM currently uses. A new input editor dubbed TRAFED is under development to provide a graphical input mechanism and will use many of the ideas from the ITRAF prototype.

CORSIM Output: The model output has several forms. Performance measures, known as the measures of effectiveness (MOE), are written to a standard ASCII file suitable for printing. Actual throughput measures such as speed, delay, emissions, and fuel consumption are computed in aggregate forms for various measurement points and in summary form for the entire transportation network. CORSIM can also generate animation files for the post-processor TRAFVU, which is a Windows program that will display the entire network including its control systems, sensors, vehicles and certain MOE. Vehicles are displayed at their corresponding positions every simulation time-step, and the control systems are updated every time step allowing TRAFVU to animate the major events that the simulation produces.

Positive Impacts: The development of a computer simulation model capable of analyzing freeway and non-freeway network traffic operations proves to fulfill an essential need. This modeling capability enables transportation officials to fully evaluate different alternative transportation system design and control strategies in determining a system solution to traffic congestion problems.

3 APPLICATIONS

The use of computer simulation to solve transportation problems continues to gain acceptance within the transportation profession. The following are recent examples of how computer simulation methods were used to help solve transportation-related problems. In these examples, the application of the TSIS/CORSIM simulation model impacted the decisions made for each case study.

3.1 Sample Application Number 1

Background: Des Moines, Iowa, working with the Iowa DOT, FHWA applied the advanced techniques within TSIS to evaluate proposed roadway interchange design alternatives in the Des Moines metropolitan area. The purpose of the project was to analyze two specific alternative designs for a particular interchange located along Interstate routes 35/80. Figure 1 illustrates the two designs being evaluated using TRAFVU. The partial cloverleaf interchange configuration seen in the lower half in the figure, and an upgraded standard diamond interchange design in the upper half of the figure. The goal of the study was to determine which design alternative provided the best overall traffic performance, given the future anticipated traffic demands.

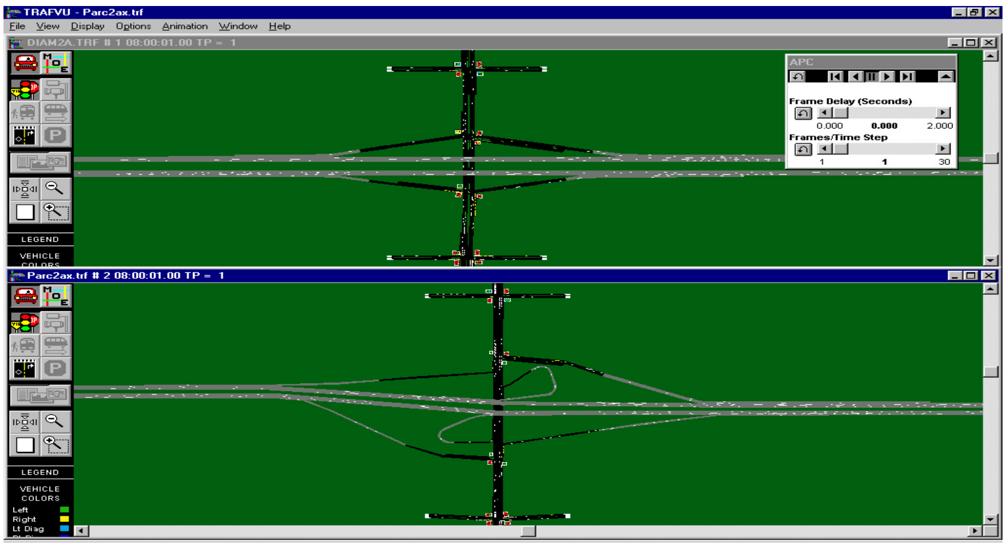

Figure 1: Des Moines, Iowa Study

Procedure: Traffic data and proposed plan drawings of the alternative interchange designs were obtained from the Iowa DOT. Included on the drawings were the roadway measurements, the number of traffic lanes, the number and type of ancillary lanes (acceleration/deceleration/auxiliary/turn lanes, etc.). For the freeway and surface streets, the Annual Average Daily Traffic (AADT), the Design Hourly Volumes (DHV), and the orientation of the interchanges and surface streets were also included.

In addition, other data such as the traffic signal timing information for the surface streets were also obtained. Other factors that proved to be important to the modeling effort were gathered, such as:

- The area served a major shopping center, motels, and numerous commercial businesses in addition to normal traffic;
- At 600 feet from the ramp termini, a frontage road would be added that would require enough traffic "green time" to create sufficient gaps for the exiting traffic;
- Lane widths, shoulder widths, and barrier widths were specified;
- The percentage of trucks on the surface streets and the freeways were also specified.

From this information, the data sets were created for input to the CORSIM model. Links (roadway sections), nodes (link intersection points), intersections and changes in geometric conditions are represented to the CORSIM model as a link-node structure. The corresponding link-node diagram was created based on the plan drawings. The street lengths were measured from the diagram and placed appropriately on the link-node diagram. All of the link geometry information (link lengths, number of lanes, and number of turn pockets) were taken from the plan drawings and used as input to the data sets. The existing and forecasted traffic volumes were obtained from the state/local DOTs. The surface street signal timings were also provided and coded into the model. Node coordinates were calculated using the length information from the plan diagram. Once the existing conditions were calibrated satisfactorily, several simulation runs for each alternative were performed.

Results: The alternative designs were simulated, refined, and expanded to incorporate various geometric and traffic-control modifications in developing a desired design/control strategy. Then, the alternative designs were further "fine-tuned", evaluated and compared. It was interesting to note that both alternative designs performed reasonably well, with the upgraded standard diamond interchange design appearing to function slightly better that the partial cloverleaf design. However, the simulation results were significant because the partial cloverleaf design was approximately $14 million more in right-of-way costs alone!

The Iowa DOT used the results of this simulation study to select a final design. Subsequently, the Iowa DOT has put together a team of transportation professionals to apply computer traffic simulation to evaluate over twenty miles of planned Interstate reconstruction activities within the Des Moines metropolitan area.

3.2 Sample Application Number 2

Background: Fargo, North Dakota: the FHWA assisted the North Dakota DOT in the application of advanced simulation methods to evaluate alternative corridor designs involving a complex series of integrated freeway and non-freeway interchanges. The purpose of the project was to investigate proposed alternative transportation strategies to provide improved access to the westside of the greater Fargo area. The traffic operational study area was the north/south Interstate 29 (I-29) and the east/west 13th Avenue corridor. The study covered approximately four square miles, bordered by Main Avenue on the north, 25th street on the east, Interstate 94 (I-94) on the south, and 45th street on the west. Emphasis was given to the I-29 and 13th Avenue corridor traffic operations.

Initial studies were conducted, yet they were limited to separate and independent evaluations of traffic operations. One evaluation centered along the 13th Avenue non-freeway corridor, while the other evaluation focused along the Interstate 29 north and south freeway corridor. These studies suggested that the proposed development plans to the area would have very little effect on the freeway traffic operations, which traverses north and south through the study area. However, concerns had been raised as to the relationship between the freeway and the non-freeway traffic network; i.e., would any of the surface street (non-freeway) traffic impact the freeway, and vice versa? Thus, the study needed to be investigated from a "system perspective", which took into account the relationship of the freeway and non-freeway traffic network as a whole.

This further "system evaluation" analysis resulted in the application of the CORSIM computer traffic simulation model of the freeway and non-freeway traffic network. The application of this state-of-the-art computer traffic simulation tool was essential to conduct a system evaluation. Specifically, the CORSIM model analyzed a network containing both the I-29 freeway and the 13th Avenue non-freeway corridor. This computer simulation program allows for the assessment of traffic impacts that system of freeways and non-freeway roadways would have on the other. It afforded the most detailed analysis capability available.

Procedure: Traffic data and proposed alternative transportation plans were obtained from the North Dakota DOT. Data and information similar to the example application discussed in Sample Application Number 1 above were obtained. The plans included, the roadway measurements, the number of traffic lanes, the number and type of ancillary lanes for the freeway and surface streets, the Annual Average

Daily Traffic (AADT), the Design Hourly Volumes (DHV), and the orientation of the interchanges and surface streets. In addition, other data such as the traffic signal timing information for the surface streets were also obtained. Other factors which proved to be important to the modeling effort were gathered, particularly the alternative freeway design components, i.e. such as shared mainline/exit lane configuration, various on/off ramp designs--including non-traditional entry ramp location, etc.

From this information, the data sets were created for numerous alternative design/control strategies as input to the CORSIM simulation model. Roadway sections, intersections, and changes in geometric conditions are represented by a link-node structure. The corresponding link-node diagram was created based on the plan drawings. The street lengths were measured from the diagram and placed appropriately on the link-node diagram. All of the link geometry information (link lengths, number of lanes and number of turn pockets) were taken from the plan drawings and used as input to the data sets. The existing and forecast traffic volumes and turning movements were provided by the DOTs, also provided were entry volumes to the network. The surface street signal timings were coded into the model as well. Node coordinates were calculated using the length information from the plan diagram. Once the existing conditions were calibrated satisfactorily, several simulation runs for each alternative were performed.

Results: The overall evaluation of the alternative transportation design/control strategies yielded different traffic operational performance. This difference is not the only significant finding. In using the simulation model, it revealed a result that would have gone unnoticed using traditional analysis techniques. Specifically, the simulation demonstrated significant freeway performance degradation due to the introduction of a non-traditional entry ramp design, where freeway speeds dropped by approximately 20 miles per hour. This type of result is not available using traditional analysis techniques. Yet, these speed differentials are significant and pose a serious safety and operational problem. Again in this case, the application of computer simulation pays big dividends to the DOT. In addition to realizing cost-savings of at least $2.5 million by eliminating the design and construction of a proposed ramp, the DOT estimated approximately $600,000 annual savings in peak-hour user costs.

3.2.1 Research Application

As mentioned earlier, the computer simulation model is also instrumental in developing new control algorithms, new traffic control systems, and new traffic sensors. These items can be effectively developed, tested, and evaluated in a controlled laboratory environment. With some of the new advanced systems in development in ITS, there is no other way to assess the value of these new technologies without disrupting normal traffic operations. A demonstration of that capability follows.

Background: A classic problem in traffic management is minimizing delay for major and minor arterials at a series of signalized intersections. This is a classic problem of coordinated intersection control. It is easy to envision an algorithm that minimizes queuing in each approach given a steady-state traffic pattern; which a fixed-time control system can adequately service. However, most traffic is not steady state, and can vary dramatically from moment to moment. In this situation a fixed-time control system cannot service the demand over the varying traffic conditions. Ideally what is needed is a control system that can *adapt* to its varying traffic conditions automatically.

At the 1997 Annual Transportation Research Board (TRB) conference, the ability to integrate the simulation with a new adaptive algorithm for intersection control and a new prototype traffic sensor was demonstrated. The adaptive control algorithm can adapt the signal phasing at the subject intersection to accommodate varying traffic conditions at and nearby the intersection. The algorithm considers not only the subject intersection but also the conditions at the neighboring intersections in its calculations. The desired goal is to minimize delay at each of the approaches to the intersection by adapting the control system based on demand.

A unique input datum to this adaptive control process is the actual queue length at the approaches to the intersection. Queue is defined as the length resulting from the number and type of vehicles waiting for a green signal on a given approach. The current state-of-the-practice sensor will provide estimated queue length, typically measured by strategic location of loop-detection sensors embedded in the pavement, yet currently deployed sensors do not measure *actual* queue length. ITS has fostered innovation in sensor technologies and a prototype of such an instrument has been developed. An advanced image processing system has been developed that uses a video camera to analyze the approaches to the intersection. The image-processing prototype analyzes the scene, and counts vehicles waiting at the intersection. The information is sent to the adaptive control process and it reacts accordingly.

TSIS, TRAFVU, and CORSIM were used as an integrated system to show that this new technology could work (at least in a laboratory environment).

Procedure: Figure 2 illustrates the conditions of the demonstration. At the lower left, TSIS executes CORSIM and the Real-Time Adaptive Control (RT-TRACS) process. Using TSIS, the RT-TRACS process is actually controlling the signal states of one of the intersections that CORSIM is modeling. This new level of interactive-ness with CORSIM is a new feature added to CORSIM by TSIS. They are two discrete processes that are using shared memory and a communications protocol defined by TSIS to interact at run-time. On a second computer, TRAFVU is configured to receive the animation data provided by CORSIM, as CORSIM is running. This provides the vehicle data required by the third computer executing the image-processing software, the Traffic Flow Visualization Camera (TFVC) shown on the right.

As the traffic situation at the intersection develops, the TFVC analyzes the scene, calculates the queue and reports the queue information to the RT-TRACS process via the network using the TCP/IP protocol. Using the queue information and phasing of the surrounding intersections, the RT-TRACS process computes the optimum signal timing for the intersection under adaptive control. Another computer is executing another copy of TRAFVU and is used to show the effects with and without the adaptive control process.

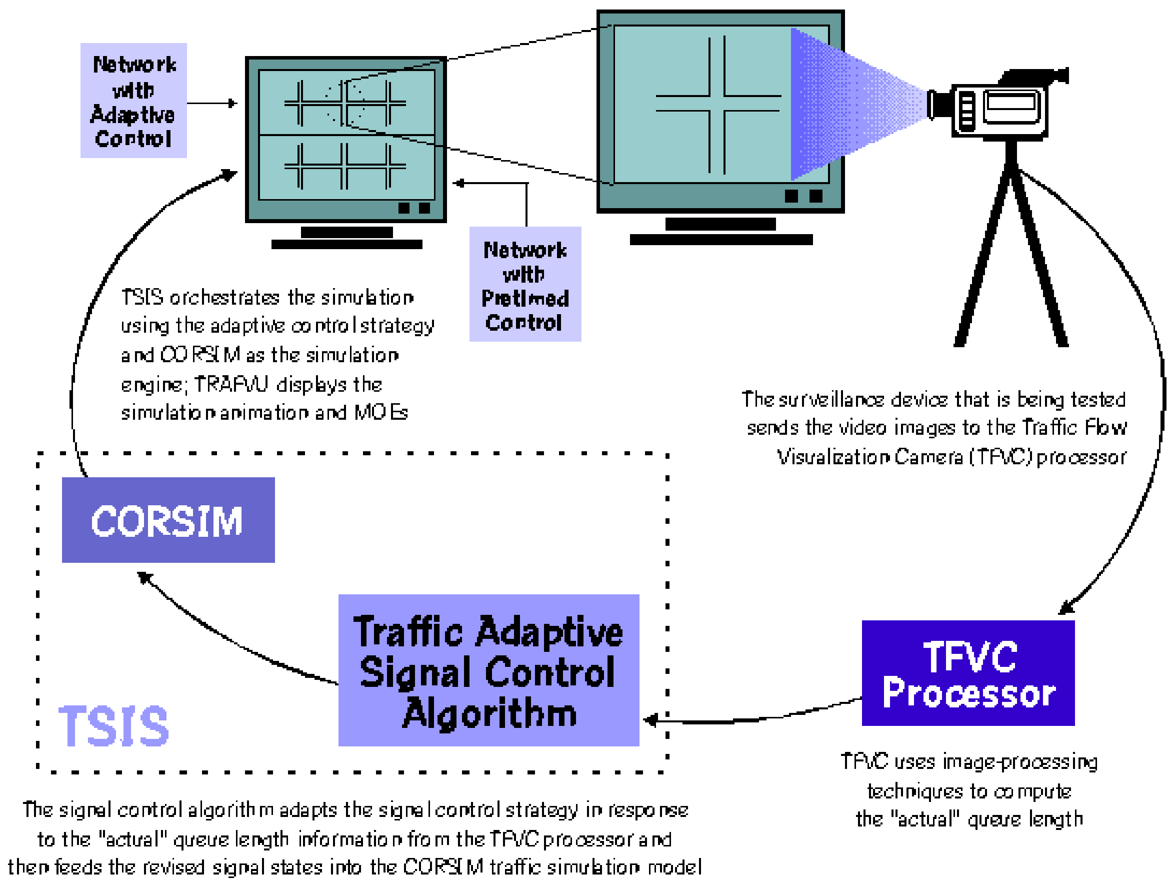

Figure 2: Adaptive Control Process

Results: The intersection was previously simulated with CORSIM using traditional fixed-time control and its animation file was stored to disk. In a multiple-window view, TRAFVU displays the effects of the fixed time control and the effects of applying the adaptive control process. The viewer can see visually that the queuing in the adaptive control process is able to serve all of the vehicles in each approach, even under variable demand. Inspecting the CORSIM MOE output files for each case, it is found that indeed, the average delay of the RT-TRACS equipped intersection was able to more effectively serve the varying traffic conditions.

Figure 3 shows that the average delay over the 30 minutes of simulation time. The simulation introduces increased demand (a traffic surge) in volume, and under fixed-time control, the delay experienced by each vehicle gets longer as volume increases.

Figure 4 shows the same intersection under adaptive-control, and as seen in the graph, the average delay stays relatively constant, even under increasing volumes. This clearly demonstrates that the adaptive control process can have an affect on traffic flow, and how the simulation tools can be used to measure the effects of the new system.

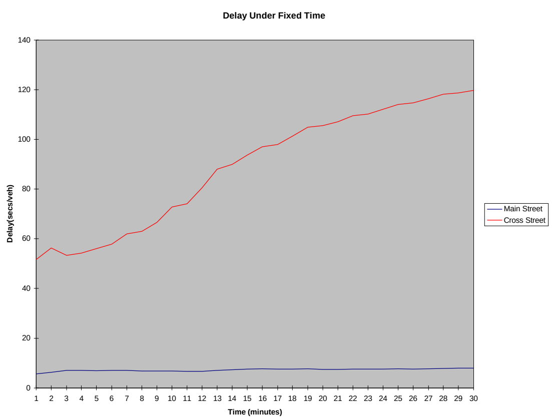

Figure 3: Fixed-Time Delay over 30 Minutes

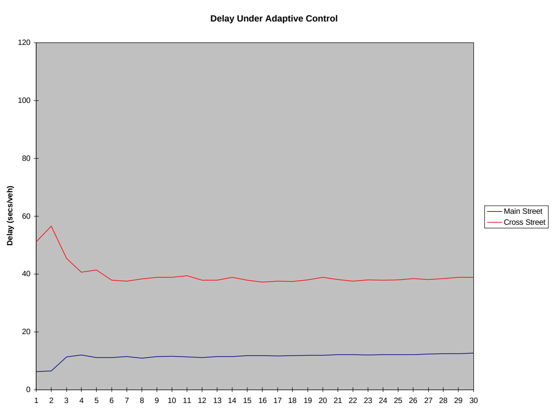

Figure 4: Adaptive-Control Delay over 30 Minutes

This demonstration illustrates the importance of the microscopic simulation to the research, development, and testing of new transportation technologies. This scenario would have been extremely difficult to accurately measure the system performance in actual field conditions. In the controlled simulation environment, the data collection process is accurate and repeatable, therefore it was easy to characterize the scenario and further, offers an opportunity to refine the RT-TRACS and TFVC algorithms before attempting a test in the field.

4 CONCLUSION

In each of the scenarios above, we have demonstrated the functionality and utility of using simulation as a tool for traffic management. In the two cases presented above, the application of traffic simulation saved several million dollars (of tax revenues) in right of way and construction costs. That does not even begin to account for the intangible savings of lost time to travelers due to the congestion created during the construction period.

The simulation tools are also vital in exploring new traffic control techniques, systems and the advanced traffic management centers of the future as seen in the research problem. Not mentioned here is another effort that is now in the demonstration phase where a live intersection controller has been integrated with TSIS and CORSIM, and the simulated intersection is actually under the control of the actual intersection control hardware. This demonstration can be used to assess the effects of different manufacturer's intersection controllers in a controlled environment, or can be an effective teaching aid.

Though the simulation model CORSIM has existed in various forms for many years, the recent advances by the insertion of advanced computer techniques and software development technology has allowed CORSIM to be taken to new levels of performance, new levels of integration and ease of use. Practitioners and researchers around the world are using the CORSIM micro-simulation model to effectively assess and improve their traffic congestion problems, and new doors are being opened each day as the computer technology moves forward.

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AUTHOR BIOGRAPHIES

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