ANL/TD/CP-101364

USING A SCALABLE MODELING AND SIMULATION FRAMEWORK TO EVALUATE THE BENEFITS OF INTELLIGENT TRANSPORTATION SYSTEMS

Thomas Ewing and Adrian Tentner

Argonne National Laboratory
9700 South Cass Ave.
Argonne, IL 60439
ewing@anl.gov

High Performance Computing 2000
Advanced Simulation Technologies Conference
The Society of Computer Simulation International

April 16-20, 2000
Wyndham City Center Hotel
Washington, D.C.

DISCLAIMER

DISCLAIMER

USING A SCALABLE MODELING AND SIMULATION FRAMEWORK TO EVALUATE THE BENEFITS OF INTELLIGENT TRANSPORTATION SYSTEMS

Thomas Ewing and Adrian Tentner
Argonne National Laboratory
Argonne, Illinois 60439 USA
ewing@anl.gov

KEYWORDS: Transportation, distributed simulation, intelligent systems.

ABSTRACT

A scalable, distributed modeling and simulation framework has been developed at Argonne National Laboratory to study Intelligent Transportation Systems. The framework can run on a single-processor workstation, or run distributed on a multiprocessor computer or network of workstations. The framework is modular and supports plug-in models, hardware, and live data sources. The initial set of models currently includes road network and traffic flow, probe and smart vehicles, traffic management centers, communications between vehicles and centers, in-vehicle navigation systems, roadway traffic sensors, incident detection algorithms, and traffic advisories. The modeling and simulation capability has been used to examine proposed ITS concepts. Results are presented from modeling scenarios from the Advanced Driver and Vehicle Advisory Navigation ConcEpt (ADVANCE) experimental program to demonstrate how the framework can be used to evaluate the benefits of ITS and to plan future ITS operational tests and deployment initiatives.

INTRODUCTION

Intelligent Transportation Systems (ITS) is a U.S. Department of Transportation (USDOT) initiative administered by the Federal Highway Administration (FHWA). ITS leverages computing and communication technologies to achieve a *smarter* system of surface transportation, offering improved safety, more efficient use of the US transportation infrastructure, and providing the traveler with enhanced choices.

USDOT has defined a common national architecture, and elements of this architecture have been deployed and tested in several ITS operational tests nationwide (Ice and Kamp 1996). Elements of the ITS architecture include such systems as satellite positioning and communication systems, in-vehicle systems which provide route guidance and other information, traffic management centers (TMC) which provide travel advisories and other information to vehicles, hazardous material tracking systems, real-time adaptive traffic signal systems, variable message signs under TMC control, vehicle collision avoidance, smart cruise controls, and other systems designed to improve the efficiency and safety of our transportation systems.

Because of the complexity of ITS and the consequences on public safety and productivity, it is essential to ensure that ITS systems under development are properly designed and function appropriately, are suitable for use by human operators, and in fact improve the efficiency of our transportation system. Sophisticated simulation tools can play a key role in the testing, evaluation, and refinement of ITS designs.

OBJECTIVES AND SCOPE

The ITS program at Argonne National Laboratory is devoted to the advancement of ITS technologies and supporting the goals of the national ITS program. A major focus of our work has been the development of modeling and simulation tools to support the study of ITS. Some of our earlier work to develop models and methodologies for an ITS simulator have been previously reported (Ewing and Tentner 1999, Hanebutte et al. 1998, Ewing et al. 1996, Doss et al. 1996). Information about the Laboratory's ITS program may be found at our web site: http://www.transportation.anl.gov/ttrdc/research/its.

This work, funded in part by the Federal Highway Administration (FHWA) and the Illinois Department of Transportation (IDOT), is designed to provide an analysis and modeling environment that incorporates the capabilities and expertise accumulated during the ADVANCE [Advanced Driver and Vehicle Advisory Navigation ConcEpt] experimental program (Argonne 1997).

ADVANCE was a FHWA-funded operational test of the use of probe vehicles for real-time traffic information. ADVANCE was conducted on an arterial and expressway network in a 300 square mile area near Chicago. The evaluation involved 75 vehicles equipped with navigation systems and position reporting capability. The vehicles served as roving probes that reported travel times to a Traffic Information Center (TIC). The TIC automatically fused data from probe reports and roadway detectors, performed incident detection, and transmitted advisories back to the ADVANCE vehicles.

The objectives of our modeling and simulation work in support of ADVANCE are:

- Integrate existing ANL ITS models into distributed, modular framework
- Utilize existing Traveler Information Center (TIC) used in the ADVANCE operational test in the simulation loop
- Recreate/extend ADVANCE tests with modeled vehicles which can dynamically reroute
- Provide environment to validate & evaluate the performance of algorithms and models against ADVANCE and other data
- Evolve into a tool to support projects in the Gary-Chicago-Milwaukee ITS Priority Corridor

The requirements for the modeling and simulation framework include:

- Distributed, scalable architecture capable of supporting large ITS problems on a network of computers (including parallel computers)
- Modular framework supporting plug-in models, hardware, and live data sources
- Visually realistic graphics displays to support training and human factors studies
- Set of initial models of ITS functionality to support the computer simulation of ADVANCE scenarios

The initial set of models currently includes road network and traffic flow, probe and smart vehicles, traffic management centers, communications between vehicles and centers, in-vehicle navigation systems, roadway traffic sensors, incident detection algorithms, and traffic advisories. The Traveler Information Center (TIC) module used in the ADVANCE operational test was fully integrated with the other models, demonstrating the capability to plug-in independently developed models and allowing a realistic simulation of the ADVANCE tests.

With the capability to handle large and complex problems beyond the scope of ADVANCE, the framework is expected to play a primary role in evaluating the benefits of ITS technologies and to support ITS development and deployment in the Gary-Chicago-Milwaukee (GCM) corridor.

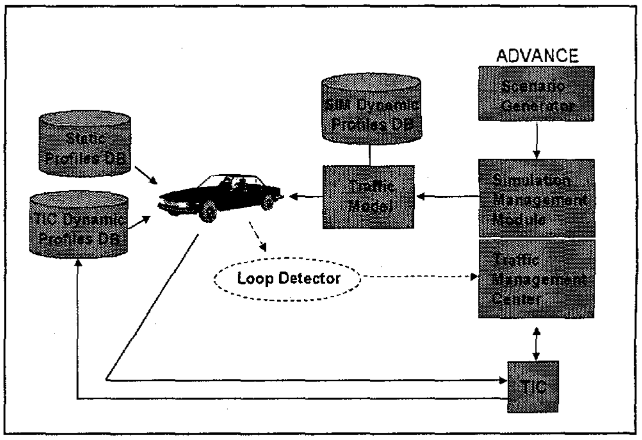

Fig. 1 – Architecture of framework showing data flow between simulation modules.

SIMULATOR IMPLEMENTATION

The framework has been developed as a set of integrated modules, each representing specific functions of an Intelligent Transportation System. The framework architecture, which is shown in Fig. 1, uses a highly modular design, selected to allow maximum flexibility for future expansion and for the use of independently developed models. It is a scalable architecture, which will allow, in the future, the use of advanced computing architectures to simulate the behavior of systems involving large numbers of intelligent vehicles.

ITS models have been written in the C language under the UNIX operating system. The graphical interface was developed in Tcl/Tk (Ousterhout 1994) so as to be platform independent. The major functional elements of the framework include map databases, scenario generator, traffic management center (TMC), vehicle model, and the TIC module from the ADVANCE project.

Networked UNIX workstations support the processing needs and graphical displays. Both the TMC view and the smart vehicle view feature detailed graphical user interfaces to support human-factors studies. The vehicles, TMC, and TIC run as distributed processes on a network of UNIX workstations.

Traffic Management Center (TMC)

The TMC module simulates the functions normally associated with a real Traffic Management Center. It is designed to receive and display information about the current traffic conditions from various sources, allowing the TMC operator to gain an understanding of the current state of the road network and to evaluate the benefits of various strategies and technologies. In the future, this module will be expanded to allow the TMC operator to influence traffic through Variable Message Signs, Traffic Signals, Road Closures, etc.

The TMC currently tracks five different types of vehicle traffic: conventional traffic, probe vehicles, and three classes of smart vehicles (cars, emergency vehicles, and trucks/buses). The smart vehicles are tracked by vehicle type to allow for the future possibility of providing each type with different treatment. For example, emergency vehicles might be given preferential routing, and trucks/buses have road weight and overpass clearance limitations that might impact their route selection.

Conventional vehicles, which form the background traffic, do not communicate position information directly to the TMC; their presence is assumed inferred by road sensors and by other means. This background traffic is represented by the average speed of conventional traffic for each link and is displayed by color-coding the road links on the TMC map display. Probe and smart vehicles, and other special vehicles, such as simulated ADVANCE experiment vehicles are individually tracked by the TMC and are depicted by distinct (color-coded) symbols on the TMC map display. Clicking on a probe or smart vehicle symbol on the TMC display selects it for tracking and pops open an attribute panel. The attribute panel for a smart vehicle indicates the vehicle type, vehicle speed and average trip speed, distance traveled, total estimated trip time and current time traveled, and time saved due to reroutes. The time saved to reroutes is an important element in estimating the benefits of ITS deployment. Future work will add fuel consumption and emission models to the vehicle module, allowing the evaluation of ITS benefits in terms of fuel savings and emission reduction.

All tracked vehicles have one-way communications with the TMC, broadcasting position information that is used to display the vehicle position and may be used to infer traffic conditions. The TMC also receives information from the Real World and the Advisory databases. The Real World information is used to display the current traffic conditions on all links, while the Advisory information is used to display the traffic delays detected by the TIC and sent to the smart vehicles for potential rerouting. The direct comparison between the Real World and Advisory information provides a useful tool for the analysis of the dynamic TIC performance in detecting incidents.

The graphical user interface (GUI) of the TMC is shown in Fig. 2. An "information everywhere" design approach was taken for the TMC GUI. Essentially, every object on the display, whether a road segment on the map display, or a vehicle symbol, can be queried by the user for attribute information. For example placing the mouse cursor over an object causes the object to be highlighted and a one-line status summary to appear. Double clicking on a smart vehicle symbol opens the data attributes panel described above, which moves on the display with the vehicle symbol. The path of travel of a smart or probe vehicle, and the reroute path of a smart vehicle can also be displayed on the map. The vehicle symbols flash to indicate that a probe report has been sent to the TIC. Each link is color-coded indicating the Real World traffic conditions, with colors ranging from green to indicate normal traffic conditions to red to indicate high congestion. When an incident is detected by the TIC, a circular symbol is drawn on the TMC display near the location of the incident. The symbol is color coded to indicate the severity of the congestion resulting from the incident, with red indicating high, orange moderate

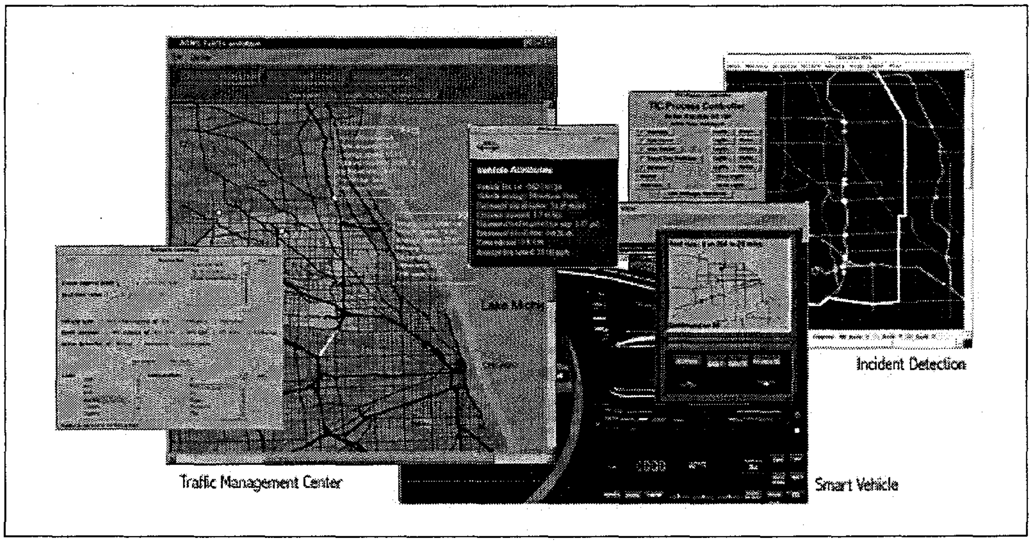

Fig. 2 -- The major modules of the modeling and simulation framework include the Traffic Management Center (TMC) module (map display on left), which provides a graphical display of vehicle, traffic, incident, and roadway information; the smart vehicle GUI (center) which provides interaction with the in-vehicle navigation system, route planning, track over map, guidance, advisories, and alternate routes; and the incident detection module (right), which detects and broadcasts potential incidents that cause congestion.

and yellow low severity.

Map Databases

The static map database used in the framework combines the road network information for the ADVANCE area, supplied by Navigation Technologies, with the Static Profiles which contain information about the traffic speed for each link at specific times of day and on specific days of the week. Road data consists of geometry information, as well as link length, type, traffic direction, and nominal speed. The University of Illinois at Chicago (UIC) originally prepared the Static Profiles for the ADVANCE project by modeling and from historical travel time information provided by the Chicago Area Transportation Study (CATS).

In addition to the static data base, with fixed, historical travel time values, the simulator employs two dynamic data bases, which contains link travel times updated to reflect the current state of the road system. For example, increased link travel times due to traffic accidents or adverse weather are reflected in the Real World dynamic profiles, stored in the Simulator dynamic profiles database. These travel times are communicated to the TIC by the probe vehicles through probe reports. The incident detection algorithm employed in the TIC analyzes differences between the static profiles and probe reports, creating the TIC dynamic profiles to project future link travel times. These TIC dynamic profiles are then sent to the vehicles through travel advisories. They are stored in the TIC Advisory dynamic database and used for in-vehicle route planning. The distinction between the Real World and Advisory databases allows not only a realistic simulation of the ADVANCE tests, but also provides a tool for evaluating the dynamic performance of the TIC module.

Traveler Information Center (TIC)

In order to recreate the ADVANCE tests in the simulator and use ADVANCE data to validate the framework capabilities, the ADVANCE TIC module that was used in the actual operational tests was imbedded in the simulation. The successful use of the ADVANCE TIC also demonstrates the flexibility of the framework architecture to integrate legacy models. The role of the TIC is to receive information from instrumented probe and smart vehicles, to fuse this information and detect unusual traffic conditions. It then broadcasts traffic advisories to the smart vehicles, informing them of traffic congestion that might require rerouting.

A two-way interface module between the TIC and the vehicle module has been developed as part of this project. Probe vehicles have one-way communications with the TIC, broadcasting position information that is used to display the vehicle position and to infer traffic conditions. Smart vehicles, on the other hand, have two-way communications with the TIC, and send traffic information to and receive advisories from the TIC. Smart vehicles thus have access to the current state of road and traffic information for route planning, and thus choose optimal routes. It is noted, however, that the TIC information is only an estimate of real world conditions, and depends on the accuracy and frequency of probe reports, as well as the TIC incident detection algorithms. Smart vehicles dynamically react to changing conditions, as detected by the TIC, and can reroute around incidents as they develop.

The Vehicle Model

The vehicle model is an essential component of the framework, allowing the computer simulation of many vehicles, with various characteristics. It allows the simulation of both probe vehicles, which transmit to the TIC information about the current traffic conditions, and smart vehicles that have two-way communications with the TIC and can and receive TIC advisories and reroute. The vehicle module also allows the simulation of vehicles used in previous experiments, which use experimental data to move from origin to destination.

The vehicle model runs as an autonomous process, and simulates a smart vehicle with optimal routing capabilities. When created, it is assigned an origin and destination, a vehicle type (probe, smart car, smart truck/bus, or smart emergency vehicle), and routing criteria (fastest route or minimum distance). When used as a probe, it calculates its route between the assigned origin and destination based on the static map profiles (historical travel times). Probe vehicles report their position to the TMC and TIC, but do not receive advisories on traffic conditions. When the vehicle is used as a smart vehicle instead of a probe, it bases its route on dynamic profile data (static profiles updated by the Advisory data base to reflect current actual conditions). Additionally, the smart vehicle receives traffic advisories broadcast by the TIC while en-route, and can dynamically reroute to avoid congestion. Smart vehicles also compute and report their time savings due to rerouting.

MODELING OF AN ADVANCE EXPERIMENT

As an example of modeling ADVANCE-like scenarios involving smart vehicles capable of dynamically rerouting, and in order to use ADVANCE data to validate the models, we recreated, through computer simulation, several ADVANCE experiments. One of these experiments, selected here for illustration purposes, was the ADVANCE yoked driver experiment 2, conducted on September 29, 1995. The objective of this experiment was to compare the

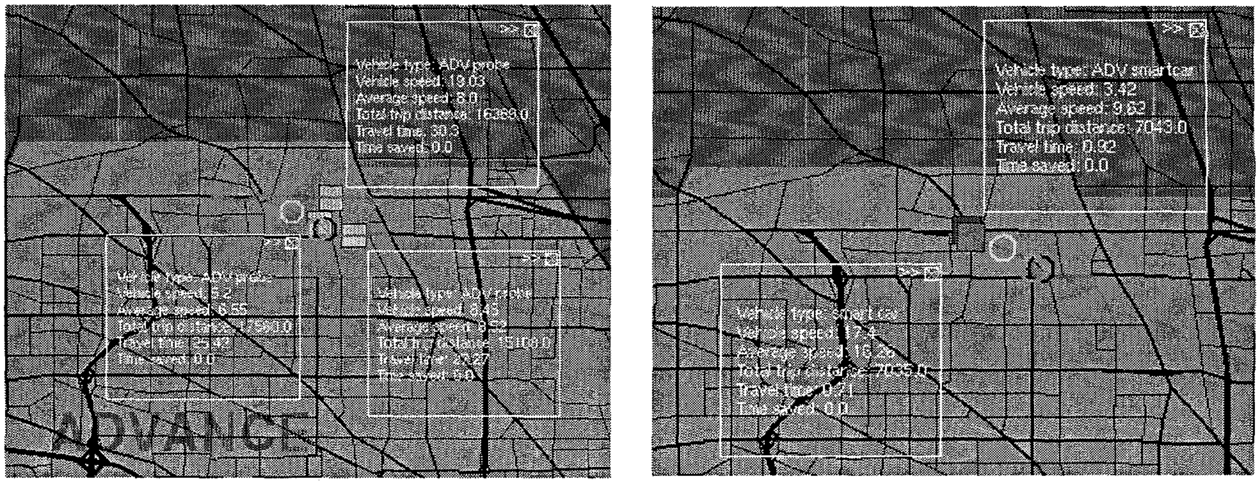

Fig. 3 – The first step (figure at left) in recreating the ADVANCE experiment was to run simulated probe vehicles (square symbols) in the correct time sequence to cause the TIC to react to the probes and broadcast advisories about the locations of congestion (circular symbols). The second step (figure at right) was to run a simulated smart car with the same origin and destination as the original ADVANCE smart car. The time-dependent track of the original ADVANCE car was superimposed on the simulation display to facilitate the comparison. The simulated smart car saw the same TIC advisories as the ADVANCE smart vehicle and made the same routing decisions.

routes and travel times of a smart vehicle with those of a static vehicle that does not receive current TIC information. A smart vehicle can dynamically re-route to avoid congestion. A static vehicle, on the other hand, drives a predetermined (static) route that does not have the benefit of knowledge about current traffic conditions, such as would be provided by an Internet routing service like mapquest.com. The experiment was conducted for a route with Buffalo Grove, Illinois as the origin and Wheeling, Illinois as the destination.

To conduct the original experiment, first several probe vehicles were driven along candidate routes to feed the TIC with data about current traffic conditions. The TIC analyzes probe reports and sends advisories to dynamic vehicles, which base their routing decisions on projected traffic conditions. After the probe vehicles had sufficiently characterized the traffic conditions to the TIC, a smart car and a static car were launched at the same time from the same location in Buffalo Grove and traveled to the same destination in Wheeling. In this particular case, the ADVANCE smart car chose an alternate route which was different from that of the static car, due to existing traffic advisories issued by the TIC. The smart car route resulted in a travel time of 10.5 minutes and a distance of 4.4 miles.

To simulate this experiment (see Fig. 3), we first ran simulated probe vehicles along the same routes originally run in the experiment, matching vehicle speed, day of week, and time of day, to insure that the TIC would receive the same data as during the actual ADVANCE experiment. The probe vehicles were created using the ADVANCE data downloaded from the web-based ADVANCE Information Source (AIS), relying on the vehicle module capability to re-create experimental vehicles. The AIS was developed at ANL as part of the ADVANCE project evaluation and can be accessed at http://ais.its-program.anl.gov.

We then started a simulated probe vehicle, at the same time as a re-created static ADVANCE vehicle. Again, the ADVANCE static vehicle was created by using the ADVANCE data, while the simulated vehicle was given only the same origin and destination, but selected its own optimal route, without having access to the Advisory database generated by the TIC. The simulated static vehicle selected the same route as the ADVANCE static vehicle, and closely followed the experimental vehicle from origin to destination.

Finally, we started a simulated smart car at the same time as a re-created dynamic ADVANCE that was used in the test analyzed. The simulated smart car, which can re-route, presumably received the same TIC advisories as the original ADVANCE dynamic car. The result was that the simulated vehicle chose the same route as the ADVANCE dynamic vehicle, and had a slightly faster en-route time of 10.1 minutes, compared to the 10.5 minutes for the experimental vehicle.

We also logged onto the Web and requested driving directions between the same origin and destination from the internet-based MapQuest system. MapQuest does not make use of actual traffic conditions, hence its routes are optimal only if traffic conditions correspond to historical averages. MapQuest selected a slightly different route than that chosen by the simulated and real ADVANCE smart cars. While the MapQuest directions estimated a nine-minute driving time assuming average conditions, it in fact selected a route that traveled through a heavily congested area that was non-optimal.

CONCLUSIONS

The ITS Modeling and Analysis Framework provides a useful tool for the modeling and analysis of many ITS issues that were studied in the ADVANCE operational test and in other ITS operational tests nationwide. The framework can model ADVANCE-like scenarios involving smart vehicles capable of dynamically rerouting, which interact with a traffic information center that detects incidents and provides traffic advisories. It also provides an estimate of travel time savings due to the use of ITS technologies in individual vehicles. While an operational test like ADVANCE is limited by budgetary and other practical constraints to a relatively small number of vehicles and trials, the distributed architecture of the modeling framework permits the analysis of cases involving various scenarios and large numbers of vehicles with relatively little additional effort and cost. Using simulation, the studies can be extended quickly to wider regions, allowing for longer trips, which can provide better statistics. Such studies can be very valuable in planning, and can help in reducing the number of costly and time-consuming operational tests. A small number of operational tests will nonetheless be necessary to confirm the computed results. Furthermore, scenarios can be designed using simulation in which the severity, location, and nature of the congestion are varied. This is not possible in an operational test using an existing arterial and expressway network.

REFERENCES

Ice, R. and T. Kamp, "Toward Practical Application of the National Architecture, FAST-TRAC as a Case Study". *Proceedings of the 1996 Annual Meeting of ITS America*, Houston, Texas. April 15-18, 1996.

Ewing, T. and A. Tentner, "A Scalable Architecture for the Modeling and Simulation of Intelligent Transportation Systems," *Proc. Of the High Performance Computing Symposium*, 1999 Advance Simulation Technologies Conference, San Diego, April 11-15, 1999.

Hanebutte, U.; E. Doss, T. Ewing, and A. Tentner, "Simulation of Vehicle Traffic on an Automated Highway System," *Mathematical and Computer Modeling Journal*, June 1998.

Ewing, T.; E. Doss, U. Hanebutte, and A. Tentner, "Simulation Framework for Intelligent Transportation Systems," *Proc of 3rd Annual World Congress on ITS*, Orlando, October 14-18, 1996.

Doss, E.; U. Hanebutte, J. Vitela, A. Brown-VanHoozer, T. Ewing, and A. Tentner, "Simulation of Highway Traffic with Various Degrees of Automation," *Proc of 3rd Annual World Congress on ITS*, Orlando, October 14-18, 1996.

The ADVANCE Project: Formal Evaluation of the Targeted Deployment, Argonne National Laboratory, Evaluation Manager, (Argonne, Illinois, January 1997).

Ousterhout, J., *Tcl and the Tk Toolkit*, Addison Wesley (1994).

ACKNOWLEDGEMENTS

This work was sponsored in part by the Federal Highway Administration and the Illinois Department of Transportation.