ANL/TD/CP-98612

A Scaleable Architecture for the Modeling and Simulation of Intelligent Transportation Systems

Thomas Ewing and Adrian Tentner

Argonne National Laboratory
ITS Program
9700 South Cass Ave.
Argonne, IL 60439

High Performance Computing '99

Advanced Simulation Technologies Conference
The Society of Computer Simulation International

April 11-15, 1999
Hyatt Islandia, San Diego, California

DISCLAIMER

DISCLAIMER

A Scaleable Architecture for the Modeling and Simulation of Intelligent Transportation Systems

Thomas Ewing and Adrian Tentner
Argonne National Laboratory
Argonne, Illinois 60439 USA

ABSTRACT

A distributed, scaleable architecture for the modeling and simulation of Intelligent Transportation Systems on a network of workstations or a parallel computer has been developed at Argonne National Laboratory. The resulting capability provides a modular framework supporting plug-in models, hardware, and live data sources; visually realistic graphics displays to support training and human factors studies; and a set of basic ITS models. The models and capabilities are described, along with a typical scenario involving dynamic rerouting of smart vehicles which send probe reports to and receive traffic advisories from a traffic management center capable of incident detection.

INTRODUCTION

The annual cost of congestion to the nation in lost productivity alone is estimated to be on the order of $100 billion, excluding the cost of wasted fuel and adverse impacts to the environment. Over 40,000 people are killed annually and another 5 million are injured in traffic-related accidents. Because the cost of rebuilding our roads to support future travel demand is prohibitive, the US Department of Transportation (DOT) has concluded that a *smarter* system of surface transportation is needed, offering improved safety, more efficient use of the US transportation infrastructure, and providing the traveler with enhanced choices (1).

To fulfill the vision of a future of safer transportation and better informed travelers, improved traffic control systems, and efficient transit operations, DOT has initiated the Intelligent Transportation System (ITS) program. Administered by the Federal Highway Administration (FHWA), ITS will use advanced computing and communications technologies for proactive control and management of traffic flow and transportation facilities.

A common national architecture has been developed by U.S. DOT, and elements of this architecture have been deployed and tested in several ITS operational tests nationwide (2). 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's) 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.

Due to the complexity of ITS and the far reaching impacts on public safety and productivity, care must be taken to ensure that any systems developed are properly designed and function appropriately, are suitable for use by human operators, and in fact improve the efficiency of our transportation system. Sophisticated simulations 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. An important objective of our program is the development of a framework for analysis and modeling of ITS. Some of our earlier work to develop models and methodologies for an ITS simulator have been previously reported (3-6)

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 which incorporates the capabilities and expertise accumulated during the

ADVANCE [Advanced Driver and Vehicle Advisory Navigation ConcEpt] experimental program (7).

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 requirements for the modeling and simulation framework include:

- a distributed, scaleable architecture capable of supporting large ITS problems on a network of computers (including parallel computers)
- a modular framework supporting plug-in models, hardware, and live data sources
- visually realistic graphics displays to support training and human factors studies
- a set of initial models of ITS functionality to support 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.

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 ITS technologies and to support ITS development and deployment in the Gary-Chicago-Milwaukee (GCM) corridor.

COMPUTING ARCHITECTURE

The computing architecture was designed from the beginning to support a distributed/parallel-processing paradigm. This permits deploying the system on a single processor workstation for modest size problems, or running distributed over several networked computers for larger simulations. Moreover, the distributed, scalable architecture of the system permits leveraging emerging massively parallel processor (MPP) systems such as the Argonne IBM SP-2 computer (8) for large-scale problems.

A key element of the architecture is that vehicles and other ITS elements are modeled as autonomous computer processes which exchange messages. Information is communicated been processes by a combination of IP network communications and shared files. Some of the implications of the architectural design are that the system:

- More closely mirrors the actual physical system simulated
- Naturally fits distributed/parallel computing model
- Inherently possesses limited fault tolerance
- Inherently scales to large problem sizes
- Supports placement of hardware-in-the-loop and live data feeds
- Promotes integration, maintainability and extensibility
- Platform independent
- Lightweight processes
- Load balance through process migration

SIMULATOR IMPLEMENTATION

ITS models have been written in the C language under the UNIX operating system. The graphical interface was developed in Tcl/Tk (9) 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.

Map Database

The map databases used in the framework, which are derived from ADVANCE, were originally prepared by the University of Illinois at Chicago (UIC) from road network information supplied by Navigation Technologies. Historical travel time data was developed by modeling and from information obtained by the Chicago Area

Transportation Study (CATS). A future goal of the database module is to provide dynamic, on-line retrieval of required map data during a simulation to reduce the memory footprint of map data required by vehicle processes.

Map data consists of geometry information, as well as link length, type, traffic direction, and nominal speed. The simulator employs two types of map databases: a static profile database with fixed, historical values, and a dynamic profile updated to reflect the current state of the road system. For example, increased link times due to adverse weather or traffic accidents are reflected in the dynamic profile. The incident detection algorithm employed in the TIC analyzes differences between the static and dynamic profiles to project future link travel times.

Scenario Generator

A scenario generator is used to generate traffic and congestion. Currently, the scenario generator provides a scrolling list of available scenarios that may be run singly or in combination. Also, individual probe or smart vehicles can be started by selecting the origin and destination, vehicle type, route selection criterion, and a real-time multiplier. The scenarios are defined by writing UNIX script files, and may include sequencing of events in time. After creating a new scenario, the user places a one-line description of the scenario and the script file name in an ASCII file that is read at startup by the scenario generator.

The scenarios generally includes such selections as simulated probe or smart vehicles along certain routes, various types of incidents at specific locations, or the replay of vehicles based on archived data from the ADVANCE experiment. The latter permits the comparison of simulated vehicles under recreated conditions with the recorded behavior of actual vehicles during an ADVANCE experiment.

Traffic Management Center

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 traffic vehicles are not individually tracked by the TMC. It is assumed that conventional vehicles *are not* communicating position information directly with the TMC; their presence is assumed inferred by road sensors. Thus, only average densities of conventional traffic for each link are displayed by color coding the road links on the TMC map display. Probe and smart vehicles, however, 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.

Probe vehicles have one-way communications with the TMC, broadcasting position information that may be used to infer traffic conditions. Smart vehicles, on the other hand, have two-way communications with the TMC, and send tracking information to and receive advisories from the TMC. Smart vehicles thus have access to the current state of road and traffic information for route planning, and thus choose optimal routes. Smart vehicles also dynamically react to changing conditions, and can reroute around incidents as they develop.

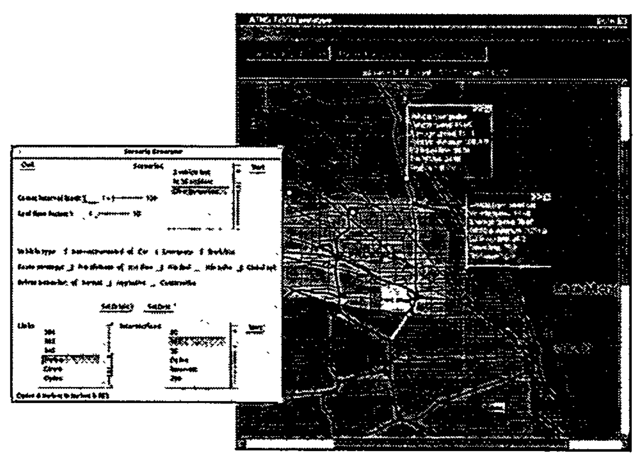

Figure 1 - The Traffic Management Center GUI (right) displays a map and information about traffic movements and incidents. The scenario generator is shown at left.

The graphical user interface (GUI) of the TMC is shown in Figure 1. 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. When an incident is detected, 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 and yellow low severity.

Smart Vehicle

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 simulation to reflect current actual conditions). Additionally, the smart vehicle receives traffic advisories broadcast by the TMC, and can dynamically reroute to avoid congestion. Smart vehicles also compute and report their time and fuel savings due to rerouting.

An advanced feature of the vehicle is the option to run it interactively with a graphical user interface, shown in Figure 2. The interactive smart vehicle permits exploring the man-machine interface implications of ITS, and features visually and functionally realistic automobile instrumentation and controls. The in-vehicle navigation/route guidance system functions like actual commercial prototypes. The system shows current location on a small map display, and permits entry of the destination and route planning strategy (minimum time or minimum distance).

If a traffic advisory is received from the TMC, the vehicle model determines if the traffic incident lies ahead on the selected route of travel of the vehicle. If the traffic

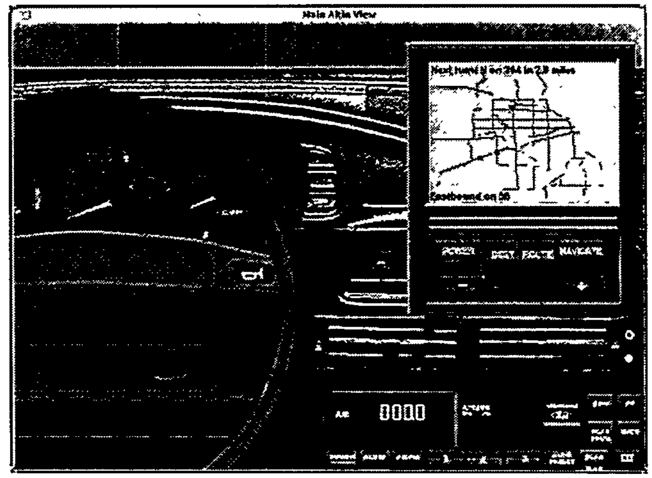

Figure 2 - The smart vehicle GUI permits interacting with the in-vehicle navigation system, which provides route planning, track over map, guidance, advisories, and alternate routes.

incident would impact the travel time by more than a specified percent, then a congestion advisory and suggested alternate route are displayed on the navigation system. Both an estimate of the delay caused by the congestion and the estimated time savings from a reroute are indicated. The new route is also tabulated on the console window to permit the user to review the new route.

If the suggested route is accepted, the vehicle process is started and the navigation system display provides directional guidance along the route. The current heading and route are displayed (e.g., Northbound on Rt. 83), and an indication of the next maneuver is given (e.g., Next turn, N on I294 in 3.5 miles). As the required turn is approached, a visual indication is given to signal when and in what direction to make the turn. If the alternate route is not accepted, the vehicle continues along the original route of travel, but the navigation system advises the driver of any additional opportunities to reroute it finds. During the simulation, the current vehicle position is continually shown on both the navigation system and the TMC displays.

CONCLUSIONS AND FUTURE DIRECTIONS

The framework provides a useful tool for the modeling and analysis of many ITS issues that were studied in the ADVANCE operational test. 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 and fuel consumption 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 large numbers of vehicles with relatively little additional effort and cost. Using simulation, the studies can be extended to a wider region than the 300 square mile ADVANCE area, allowing for longer trips, which can provide better statistics. 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. In proposed follow-on work, we plan to extend this modeling and analysis work to characterize the impact of various ITS deployment strategies on travel time, fuel consumption, and vehicle emissions in the Chicago region.

SUMMARY

The ITS modeling effort at Argonne National Laboratory is directed at advanced modeling and simulation needed to support emerging ITS technologies. A capability has been developed for a large scale, comprehensive modeling of an Intelligent Transportation System running on distributed computer systems or massively parallel computer systems.

The simulator includes the modeling of "smart" vehicles capable of optimal route planning and Traffic Management Centers (TMC) which track and analyze vehicle traffic. The TMC also provides traffic advisories to smart vehicles, which makes it possible for them to reroute automatically to avoid congestion. Both the in-vehicle instrumentation and the TMC displays are modeled with functionally and visually realistic to support human-factors studies.

Current efforts have focused on imbedding the ADVANCE TIC into the framework to demonstrate the ability to support hardware-in-the-loop and reuse of legacy components, and support modeling of ADVANCE-type scenarios.

REFERENCES

1. "Automated Highway System (AHS) -- System Objectives and Characteristics," National Automated Highway System Consortium (Troy, Michigan, November 3, 1995).
2. R. Ice 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.
3. T.F. Ewing et al, "Argonne Simulation Framework for Intelligent Transportation Systems," *Proc. Of 6th Annual ITS America Meeting*, Houston, April 15-18, 1996.
4. T.F. Ewing et al, "Simulation Framework for Intelligent Transportation Systems," *Proc of 3rd Annual World Congress on ITS*, Orlando, October 14-18, 1996.
5. T.F. Ewing et al, "Simulation of Highway Traffic with Various Degrees of Automation," *Proc of 3rd Annual World Congress on ITS*, Orlando, October 14-18, 1996.
6. U. Hanebutte, E. Doss, T. Ewing, and A. Tentner, "Simulation of Vehicle Traffic on an Automated Highway System," *Mathematical and Computer Modeling Journal*, June 1998.
7. The ADVANCE Project: Formal Evaluation of the Targeted Deployment, Argonne National Laboratory, Evaluation Manager, (Argonne, Illinois, January 1997).
8. Gropp, W., Lusk, E., and Pieper, S.C., "Users Guide for the ANL IBM SP1", Argonne National Laboratory Report, ANL/MCS-TM-198 (October 1994).
9. J. Ousterhout, "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.