CONF-960444--2
ANL/TD/CP--89234

Argonne Simulation Framework for Intelligent Transportation Systems*

Thomas Ewing, Ezzat Doss, Ulf Hanebutte, Thomas Canfield,
Alenka Brown-VanHoozer, and Adrian Tentner

Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439 USA

ITS America Six Annual Meeting,
April 15-18, 1996
Houston, Texas

*Work supported by the U.S. Department of Energy, Nuclear Energy Programs under Contract W-31-109-ENG-38

ARGONNE SIMULATION FRAMEWORK FOR INTELLIGENT TRANSPORTATION SYSTEMS

Thomas Ewing, Ezzat Doss, Ulf Hanebutte, Thomas Canfield,
Alenka Brown-VanHoozer, and Adrian Tentner
Argonne National Laboratory
Argonne, Illinois 60439 U.S.A.

Abstract

A simulation framework has been developed which defines a high-level architecture for a large-scale, comprehensive, scalable simulation of an Intelligent Transportation System (ITS). The simulator is designed to run on parallel computers and distributed (networked) computer systems; however, a version for a stand alone workstation is also available. The ITS simulator includes an Expert Driver Model (EDM) of instrumented "smart" vehicles with in-vehicle navigation units. The EDM is capable of performing optimal route planning (based either on minimum distance or on minimum travel time) and communicating with Traffic Management Centers (TMC). A dynamic road map data base is used for optimum route planning, where the data is updated periodically to reflect any changes in road or weather conditions. The TMC has probe vehicle tracking capabilities (display position and attributes of instrumented vehicles), and can provide 2-way interaction with traffic to provide advisories and link times. Both the in-vehicle navigation module and the TMC feature detailed graphical user interfaces that includes human-factors studies to support safety and operational research. Realistic modeling of variations of the posted driving speed are based on human factor studies that take into consideration weather, road conditions, driver's personality and behavior and vehicle type.

The simulator has been developed on a distributed system of networked UNIX computers, but is designed to run on ANL's IBM SP-X parallel computer system for large scale problems. A novel feature of the developed simulator is that vehicles will be represented by autonomous computer processes, each with a behavior model which performs independent route selection and reacts to external traffic events much like real vehicles. Vehicle processes interact with each other and with ITS components by exchanging messages. With this approach, one will be able to take advantage of emerging massively parallel processor (MPP) systems.

Introduction and Background

The Intelligent Transportation System (ITS) program of the U.S. Department of Transportation (U.S. DOT) is designed to use advanced computing and communications technol-

DISCLAIMER

ogies for proactive control and management of traffic flow and transportation facilities in order to improve traveler's safety and mobility, reduce congestion, minimize energy consumption and negative environmental impact, and promote economic competitiveness of the U.S. industry. The development of a common framework or system architecture for ITS, intended to promote nation-wide compatibility under the leadership of the U.S. DOT, is under way (1,2). Some of the elements of the ITS architecture under consideration include in-vehicle navigation systems; Traffic Management Centers which provide travel advisories and other information via roadside kiosks, variable message signs, and directly to appropriately instrumented vehicles; probe vehicles and roadway sensors for travel time and traffic flow measurements; real-time, adaptive traffic control systems; and communication systems.

Due to the complexity of ITS and the far reaching impacts on public safety (3) and productivity, care must be taken to ensure that any newly created system is properly designed and satisfies its functional requirements. Furthermore, its suitability for use by human operators, and its effect on the efficiency of the transportation system as a whole must be carefully assessed. Sophisticated simulators will play a key role in testing, evaluating and refinement of ITS designs.

The simulation of vehicle based surface transportation is a broad and complex research field. For brevity, only closely related work is enumerated here. The theory of traffic network simulations can be found in Refs. (4,5), while the various models describing car-following are summarized in Ref. (6). Testimony of current large scale traffic simulators performed on serial and parallel supercomputers are given in Refs. (7-11). A noteworthy simulator with emphasis on the Automated Highway System has been developed by the California Path project (12).

Argonne ITS Simulator

The ITS Simulation effort at Argonne National Laboratory is directed at advanced modeling and simulation needed to support emerging ITS technologies. A computer simulator has been developed to define the architecture for a large scale, comprehensive simulation of an Intelligent Transportation System running on distributed or parallel computer systems as well as on stand-alone workstation or.

One objective of this effort is to be able to model scenarios involving mixed traffic of conventional vehicles and instrumented "smart" vehicles possessing in-vehicle navigation and 2-way communications with TMC's. Such a pilot program called ADVANCE (13) is currently being deployed in the Chicago area involving a large number of instrumented test vehicles. The broader scope of our simulator project is to be able to support other evolving ITS programs.

Six major technical components are included in Agonne's simulation framework:

- Computing architecture
- Map database
- Scenario generator
- TMC interaction
- "Expert Driver Model" (EDM) for instrumented "smart" vehicles
- Human factors studies

Discussion of each of these topics follows.

Computing Architecture

In formulating an architecture for the ITS simulator, a clean-slate approach, from the ground up, has been adopted so as not to be encumbered by existing codes and strategies that might limit achieving a general, extensible framework to support large-scale, comprehensive ITS simulations. Another tenet of the computing architecture is to design from the beginning for distributed/parallel computing. For example, a port to Argonne's IBM SP-X parallel computer (14) to permit larger problems to be simulated and to perform scalability studies is currently under way.

A key element of this architecture is that vehicles and ITS infrastructure elements are modeled as autonomous computer processes; vehicle processes interact with each other and ITS components by exchanging messages (Figure 1).

Some of the implications of this approach are that it:

- More closely mirrors reality
- 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

The distributed simulation environment is implemented in a manner that achieves limited fault tolerance. Smart vehicle processes broadcast probe data to TMC processes, while TMC processes integrate information and broadcast advisories to vehicles. If a TMC process fails, another may be started without affecting existing vehicle processes. Similarly, vehicle processes may fail without impacting other vehicle or TMC processes. Information is communicated between processes by a combination of IP network communications and through NFS file access.

Map Database

Maps for the simulator are currently input manually in the prototype. For example, the database for the Chicago Metropolitan highway system and major arteries has been generated and used in the simulator. It includes several hundred nodes and road links, with link distant, type, traffic direction, and speed limits. Two versions of the map database are used during the simulation; one is static, where the information is basically fixed; while the other is dynamic, where the information is updated periodically to reflect any changes in road or weather conditions. Such changes and updates are expected to come from the TMC. Currently, a more robust map database module is under development. It will feature an interactive GUI for extracting the required maps from a NavTech database. A future goal is to have on-line, dynamic retrieval of required map information during a simulation.

Scenario Generator

The scenario generator is designed to generate relatively large numbers of vehicle processes to populate the simulation map quickly. As a second option, the scenario generator enables one to start individual vehicles by selecting origin and destination from a scrolling list of choices, and then selecting vehicle type, route strategy, and driver behavior from a series of check boxes.

Networked Unix workstations support processing needs and graphical displays. Both the in-vehicle navigation module (Figure 2) and the TMC (Figure 3) feature detailed graphical user interfaces to support human-factors studies. The standard graphical user interfaces run on X11-based graphical workstations.

Traffic Management Center (TMC)

At the moment, the TMC module monitors data originating from the simulated probe vehicles and static sensors. However, in its final design stage, the TMC module will detect and assess traffic problems and attempt to mitigate traffic congestion by issuing traffic advisories, link speeds, routing guidance, and by controlling ramp metering and traffic signal timing. At present, traffic incidents can be manually triggered at any time within a simulation by reducing speed limits, thus increasing travel times on links. The information is communicated from the TMC to instrumented vehicles, which then determine if the affected link lies on the route of travel. If it does, a route planning calculation is initiated to determine if a revised route is advantageous.

Expert Driver Model (EDM)

The instrumented "smart" vehicles are driven by global and local Expert Driver Models. The global EDM includes an optimum route planning capabilities and 2-way communications with TMC's. Vehicle processes can be started either from a traffic scenario generator panel (shown in Figure 3) or the detailed smart vehicle module display (Figure 2). The local EDM includes vehicle-vehicle interaction, where work is underway to consider different driving scenarios.

In the global EDM, two route planning options are currently supported. Either a minimum distance or a minimum travel time calculations is performed by each individual instrumented vehicle process using map database and TMC traffic updates. Additional options will be added in the future to permit other optimization goals, such as minimization of fuel. In this context, the use of genetic algorithms for global optimization to enhance the TMC capabilities for traffic congestion mitigation is also investigated.

Even though, only the smart vehicles will get updated information from the TMC regarding the road conditions and speed limits, the other conventional vehicles will experience the changes, without having the option to change their routes.

Currently, the instrumented vehicles and TMC's are modeled as autonomous computer processes which communicate by exchanging messages. Conventional, non-instrumented vehicles can also be modeled as autonomous computer processes; however, for computational efficiency in the current prototype, non-instrumented vehicles are treated in a macroscopic, flow model approach. The instrumented vehicles thus move in a background flow of conventional vehicle traffic.

The detailed smart vehicle module (Figure 2), on the other hand, is geared more towards human factors studies, 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, prompts for the destination using street names and intersections, then performs route planning to achieve optimal routing to the selected destination. During the simulation, the current vehicle position is continually shown on both the navigation system and the TMC displays.

Human Factors Studies

The detailed EDM for the "smart" vehicles is geared more towards human factor studies. At present, information based on such studies are extracted to determine, among others, the variational speeds of the vehicle from the nominal posted values. A 3-dimensional data matrix is stored as an input data file for the EDM. The speed variations in this matrix are functions of three variables:

- type of driver (3):
  - aggressive, nominal (aggressive/conservative), conservative
- weather conditions (13)
  - clear
  - rain/snow (light, medium, heavy)
  - fog (light, medium, heavy)
  - wind (light, medium, heavy)
  - freeze (light, medium, heavy)
- road conditions (6)
  - smooth, rough, tarred, loose gravel, construction zone (straight or curved road)

At present, this matrix is applied to conventional passenger cars. However, similar matrices will be included in the future to cover other kinds of vehicles (e.g. truck, emergency vehicles, bus, etc.)

Summary and Conclusions

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

The prototype includes the modeling of instrumented "smart" vehicles with in-vehicle navigation units capable of optimal route planning and Traffic Management Centers

(TMC). The TMC has probe vehicle tracking capabilities (display position and attributes of instrumented vehicles), and can provide 2-way interaction with traffic to provide advisories and link times. Both the in-vehicle navigation module and the TMC feature detailed graphical user interfaces to support human-factors studies.

Current efforts are directed toward the development of additional features such as the interactive GUI for the map database module, vehicle-vehicle interaction for the local EDM, improved traffic optimization using genetic algorithms, and the modeling of interactions between smart and conventional vehicles.

Acknowledgment

The work is supported by the U.S. Department of Energy under Contract W-31-109-ENG-38.

References

1. Hall, R.W. Lo, H.K., and Minge, E., "Organization for IVHS: Computer Integrated Transportation", *Transportation Research Board 74th Annual Meeting*, Washington, DC January 22-28, 1995.

2. Heft, R.C., McQueen, B., Fox, H., "System Architecture Development for ATT in Europe and IVHS in the USA", *Proceedings of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems*, Paris, France, Dec 1994.

3. Tijerina, L., "Key Human Factors Research Needs in IVHS Crash Avoidance", *Transportation Research Board 74th Annual Meeting*, Washington, DC January 22-28, 1995.

4. Sheffi, Y., *Urban transportation networks: Equilibrium analysis with mathematical programming methods*, Englewood Cliffs, N.J., Prentice-Hall, 1984.

5. Nagurney, A., *Network Economics, A Variational Inequality Approach*, Kluwer Academic Publishers, Norwell, Mass, 1993.

6. Brackstone, M., and McDonald, M., "Validity of Microscopic Modelling of Moterway Traffic", *Proc. of the Intelligent Vehicle Symposium*, Paris, 24-26 Oct. 1994.

7. Ewing, T.F., Canfield, T., Hanebutte, U.R., Levine, D. and Tentner, A., "Large-Scale Intelligent Transportation Systems Simulation," *Proc. High Performance Computing '95* (part of the1995 International Simulation Conference), Phoenix, Arizona, April 9-13, 1995, p. 253-257.

8. Nagel, K. and Schleicher, A., "Microscopic traffic modeling on parallel high performance computers," *Parallel Computing 20, p. 125-146*, 1994.

9. Mc Arthur, D., Cameron, G. and Smith, M. "Parallel Microscopic Simulation of Traffic on the Scottish Trunk Road Network,"*Proc. ISATA*, October 1994.

10. Kerridge, J. et al., "Modelling Vehicle Behaviour in Congested Networks Using Highly Parallel Systems," *Proc. of the 74rd Annual Meeting of Transportation Research Board*, Washington, DC, January 1995.

11. Boyce, D.E., Tarko, A., Berka, S. and Zhang, Y.,"Estimation of link travel times with a large network flow model for a dynamic route guidance system",*Proc. of IVHS America*, Atlanta, Georgia, April 17-20, 1994, p. 37-43.

12. Eskafi, F., and Khorramabadi, D., *Smart Path User's Manual, Technical Report UCB-ITS-94-2*, University of California, Institute of Transportation, 1994.

13. Legas, J.F. and Bowcott, S., "Progress on the ADVANCE Project", *Proceedings of the IVHS America 1994 Annual Meeting*, Atlanta, Georgia April 17-20 1994.

14. 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).

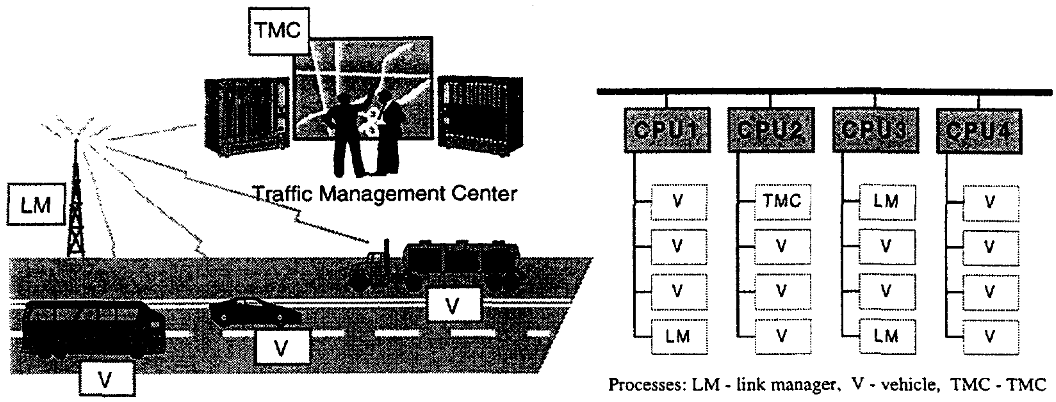


Figure 1 System Architecture

Vehicles, road-side communications, and TMC's are modeled by autonomous computer processes (left) which communicate by exchanging messages. These processes are mapped to physical processors in distributed or parallel computer systems (right) to efficiently distribute the computational effort.

Figure 2

The smart vehicle module, which features functionally and visually realistic controls and navigation system, couples with other components of the simulator and is useful for human factors studies.

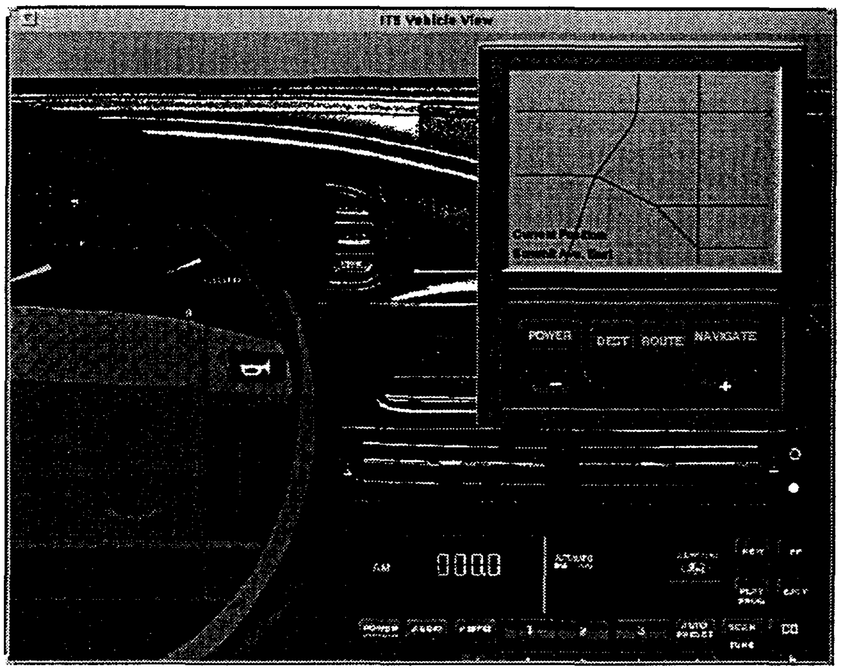
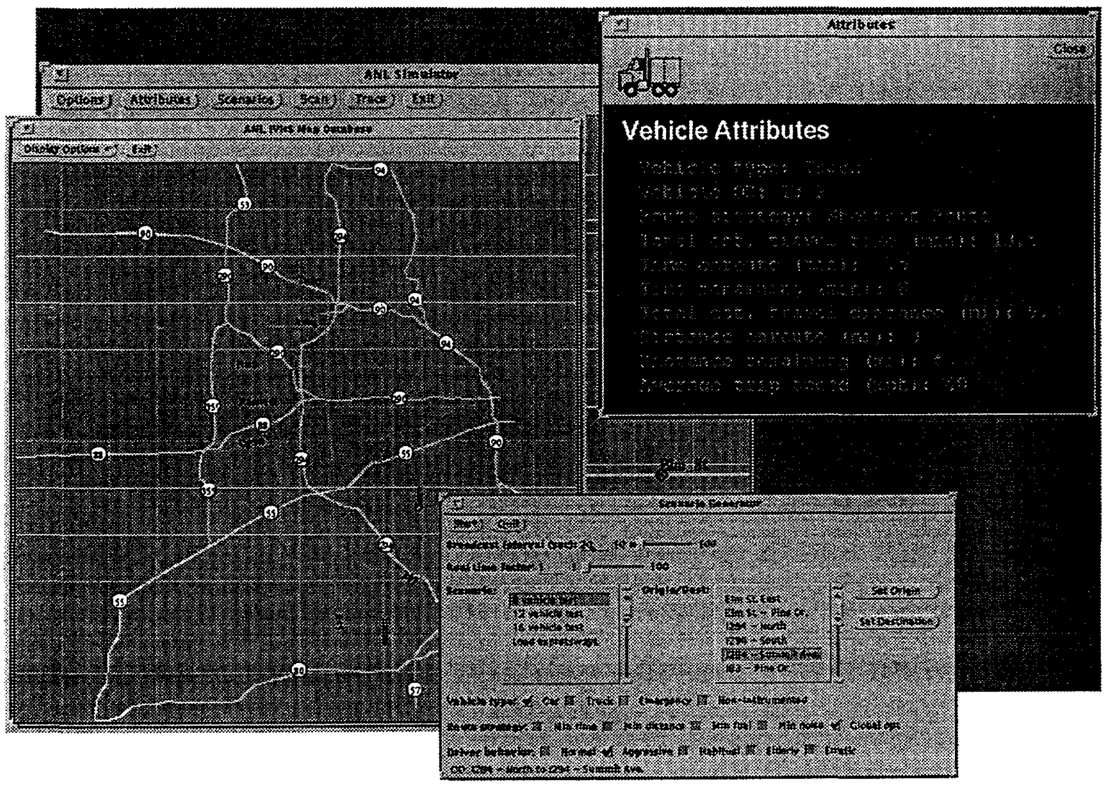


Figure 3

Traffic Management Center display showing tracking and attribute query functions. Panel at lower right is the scenario generator interface.



List of Figures: