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SIMULATION FRAMEWORK FOR INTELLIGENT TRANSPORTATION SYSTEMS*

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ABSTRACT

A simulation framework has been developed for a large-scale, comprehensive, scaleable simulation of an Intelligent Transportation System (ITS). The simulator is designed for running on parallel computers and distributed (networked) computer systems, but can run on standalone workstations for smaller simulations. The simulator currently models 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 two-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. Realistic modeling of variations of the posted driving speed are based on human factors studies that take into consideration weather, road conditions, driver personality and behavior, and vehicle type.

The prototype has been developed on a distributed system of networked UNIX computers but is designed to run on parallel computers, such as ANL's IBM SP-2, for large-scale problems. A novel feature of our approach is that vehicles are represented by autonomous computer processes which exchange messages with other processes. The vehicles have a behavior model which governs route selection and driving behavior, and can react to external traffic events much like real vehicles. With this approach, the simulation is scaleable to take advantage of emerging massively parallel processor (MPP) systems.

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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. Moreover, over 40,000 people are killed annually and another 5 million injured in traffic-related accidents. 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.

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) with a budget for FY 93-97 of $1.2 billion, ITS will use advanced computing and communications technologies for proactive control and management of traffic flow and transportation facilities.

Elements of ITS under consideration include satellite positioning and communication services, in-vehicle navigation systems which provide route planning and guidance, traffic management centers (TMC's) which provide travel advisories and other information to vehicles, automatic vehicle identification, variable message signs under TMC control, vehicle collision avoidance, and enhanced traffic control systems [1].

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 simulators can play a key role in the testing, evaluation, and refinement of ITS designs.

OBJECTIVES AND SCOPE

The ITS Simulation effort at Argonne National Laboratory is devoted to the advancement of ITS technologies and supporting the goals of the national ITS program. The objective of the simulator program is to gain a better understanding of ITS issues and the relationships between various ITS elements, scenarios, and system parameters. We are further interested in evaluating the characteristics and performance of various ITS architectures [2,3]. The scope of the simulator includes development of a model of an intelligent transportation system for the Chicago metropolitan area.

The simulator includes several ITS element models:

- road network and traffic flow
- traffic management centers
- in-vehicle navigation systems

- communications between vehicles and centers
- variable message signs
- traffic signals

Of these elements, the first four are operational, and the remaining elements are under development.

The simulator features visually and functionally realistic graphical user interfaces to support human factors work (4). Currently, there are two principle views into the simulator: a smart vehicle and a traffic management center. Smart vehicles possess in-vehicle navigation capabilities and perform optimal routing. Traffic management centers perform tracking and analysis, and provide traffic advisories to vehicles. This permits smart vehicles to automatically reroute around congestion. The simulator also has the potential to use live data feeds for highway traffic flows, permitting the simulated vehicles to respond to real traffic in real time. The simulator can operate in real time or faster than real time modes. The simulator is fully interactive in the sense that the user can respond to simulator events and impose inputs at the TMC and smart vehicle consoles, which in turn influences the later course of events.

COMPUTING ARCHITECTURE

The simulation architecture was designed from the beginning to support a distributed/parallel processing paradigm. This permits deploying the simulator on a single processor workstation for modest size problems, or running distributed over several networked computers for larger simulations. Moreover, the scaleability of the simulator permits leveraging emerging massively parallel processor (MPP) systems such as the Argonne IBM SP-2 computer (5) for large-scale problems.

The architecture of the simulator is shown in Figure 1. 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 through NFS file access. Some of the implications of the architectural design are that the simulator:

- 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

The simulator has been implemented in the C language under the UNIX operating system. The major functional elements of the simulator include a map database, scenario generator, traffic management center (TMC), and vehicle model.

Networked UNIX workstations support processing needs and graphical displays. Both the TMC view and the smart vehicle view feature detailed graphical user interfaces to support human-factors studies (Figure 2). The standard graphical user interfaces run on X11-based graphical workstations. Ve-

hicle processes may be run on Argonne's IBM SP-2 parallel computer or a network of UNIX workstations for large problems.

Map Database

Maps for the simulator are currently entered manually as data. A Chicago metropolitan highway system with major arterials consisting of several hundred nodes and links has been prepared. A database module featuring an interactive graphical user interface for extracting the required maps from a NavTech database is now undergoing testing. A future goal of the database module is to provide dynamic, on-line retrieval of required map data during a simulation.

Map data consists of geometry information, as well as link length, type, traffic direction, and speed limit. Two types of map databases are employed by the simulator: a static version with fixed, nominal values, and a dynamic map which is frequently 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 maps. Differences between the two maps are analyzed by the TMC to detect incidents.

Traffic Management Center

The TMC (Figure 2a) 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 because cars, emergency vehicles, and trucks or buses each have requirements and that may require 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 directly with the TMC; their presence is assumed to be 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 up an attribute panel. The attribute panel for a smart vehicle, for example, lists the vehicle type, vehicle origin and destination, route strategy (currently minimum time or minimum distance), total estimate travel time, current time enroute, total estimated travel distance, current distance enroute, and average trip speed.

Probe vehicles have one-way communications with the TMC, broadcasting position information which 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.

Scenario Generator

A scenario generator (Figure 2a) is used to generate relatively large numbers of vehicle processes to populate the simulation map quickly. Individual vehicles may also be started by selecting the origin and destination at arbitrary road intersections, and then selecting vehicle type, route strategy, and driver behavior from a series of check boxes. Moreover, the scenario generator can be used to trigger simulated traffic incidents, such as accident scenarios, rush hour traffic, etc.

Incidents are currently characterized by increased travel time on specified links. That is, our current incident detection model is based on scanning for higher-than-expected average link travel times. Incidents are graded according to severe, moderate, or limited. Links were an incident has been detected are color coded on the TMC map display (red, orange, yellow for severe, moderate, and limited, respectively). The travel times for affected links are also broadcast to the smart vehicles as part of TMC travel advisories. Currently, no attempt is made to characterize an incident as an accident versus congestion, etc. However, this is a future goal in order to model incident management.

Smart Vehicle

The detailed smart vehicle display shown in Figure 2b is used to explore 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). After calculating an optimal route to the selected destination, the simulated nav unit display indicates the estimated time of travel and distance for the selected route. The route may be accepted, or an alternate route strategy requested. The suggested route is also tabulated in the display console.

If the suggested route is accepted, the vehicle process is started and the nav unit 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 and audible indication is given to signal when and in what direction to make the turn.

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 incident would impact the travel time by more than a specified percent, then a congestion advisory and suggested alternate route are displayed on the nav unit. 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 route is accepted, the vehicle "drives" the new route, providing directional guidance on the nav unit display. If the alternate route is not accepted, the vehicle continues along the original route of travel, but the nav unit 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.

PRELIMINARY MODELING WORK

The simulator is still under active development, however some preliminary work has been performed in two major areas. The first area is human factor studies to characterize the variation in vehicle speed from posted limits for a matrix of three driver types, 13 weather conditions, and 6 road conditions. This effort is part of research described in a separate paper submitted to this conference (Doss et al, "Simulation of Highway Traffic with Various Degrees of Automation," submitted for publication).

The second area is a simulation-based study comparing travel times between smart cars (outfitted with in-vehicle navigation and which receive traffic advisories from the TMC) and conventional cars under various conditions. Table 1 shows the comparison in travel times for five different scenarios involving congestion due to accidents or roadway repairs in the Chicago area. This is an attempt to characterize the possible savings in travel time possible by smart vehicles (representing a small fraction of the total vehicle population) under various common congestion scenarios. [It is hoped that some validation of these travel times by actually driving the original and alternate routes will be available for the final

manuscript.] These results suggest that, in the Chicago metropolitan area, where numerous alternate routing options are possible, that substantial reductions in congestion delays are possible, often better than halving the delays that would otherwise occur without rerouting. Future studies will examine the opportunities for reducing congestion delays when a significant percentage of the vehicles have the opportunity to reroute, for example, due to an advisory provided by a variable message sign.

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 capability has been developed for a large scale, comprehensive simulation of an Intelligent Transportation System running on distributed computer systems or massively parallel computer systems.

The simulator includes the modeling of instrumented "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.
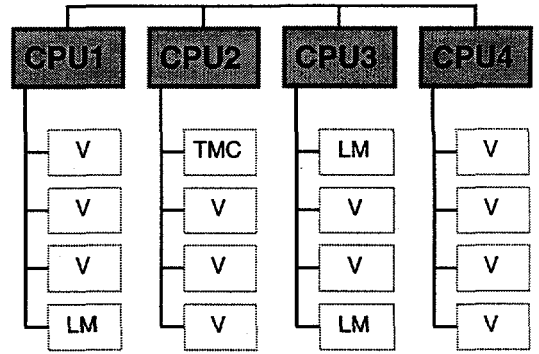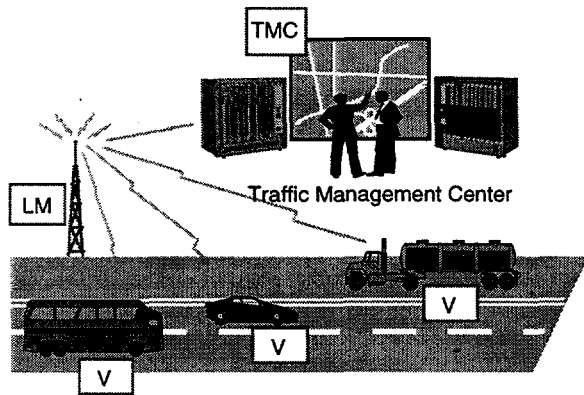
Current efforts are focused on developing additional features such as an interactive graphical user interface for the map database, enhanced vehicle-vehicle interactions, and the development of additional models to extend the functionality and fidelity of the ITS simulator.

ENDNOTES

1. "Automated Highway System (AHS) -- System Objectives and Characteristics," National Automated Highway System Consortium (Troy, Michigan, November 3, 1995).

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

4. Louis Tijerina, "Key Human Factors Research Needs in IVHS Crash Avoidance", Transportation Research Board 74th Annual Meeting (Washington, DC January 22-28, 1995).

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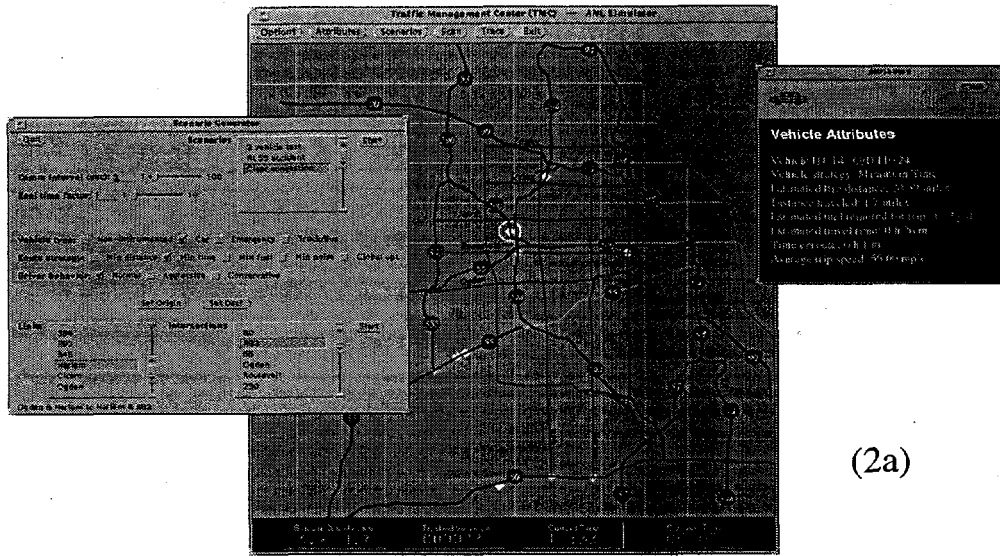
ACKNOWLEDGEMENTS

Processes: LM - link manager, V - vehicle, TMC - TMC

Figure 1   High level system architecture.

(2a)

(2b)

Directional guidance
along optimal route
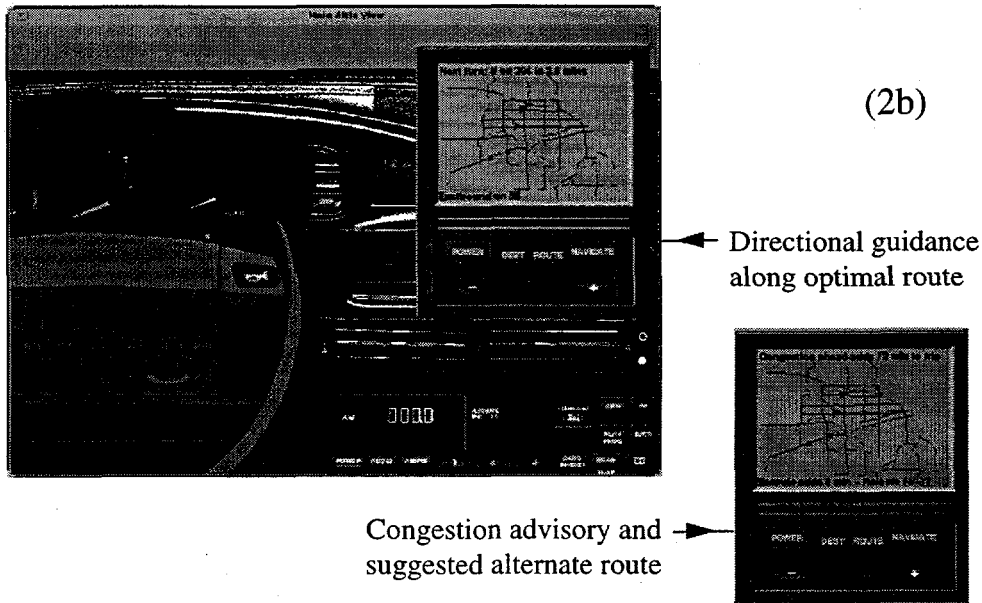
Congestion advisory and
suggested alternate route

Figure 2   Graphical user interface of Traffic Management Center display (2a) showing tracking/analysis functions and scenario generator panel, and the smart vehicle display (2b) showing vehicle nav unit.

Travel Scenario	Normal Travel Time w/o Incident	Incident Location :: Reroute Action	Smart Car Travel Time w/ Incident	Normal Travel Time w/ Incident
O'Hare to Argonne via I190/I294/I55	26.8	Accident at 294/Ogden :: I88/R83/I55	32.4	65.7
Oaklawn to O'Hare via I294/I190	25.0	Accident at 294/Ogden :: I55/R83/I88/I294	35.5	63.9
Plainfield to O'Hare via I55/I355/I88/I294	37.1	Road repairs at I88/Oakbrook :: I88/R83/Roosevelt /I294	41.7	51.3
Downtown Chicago to Oakbrook via I290/I88	17.3	Road repairs on I290 :: Roosevelt/Harlem/I290	22.8	41.1
Rt. 53 (Lake-Cook) to Argonne via R53/I355/I55	37.2	Accident on I355 :: R53/I290/I294/I55	40.0	61.2

Table 1   Effect of Smart Car Reroutes on Travel Times (minutes) in the Chicago Metro Area.

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