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Simulations of Highway Traffic with Various Degrees of Automation*

by

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ABSTRACT

A traffic simulator to study highway traffic under various degrees of automation is being developed at Argonne National Laboratory (ANL). The key components of this simulator include a global and a local Expert Driver Model, a human factor study and a graphical user interface. Further, an Autonomous Intelligent Cruise Control (AICC) which is based on a neural network controller is described and results for a typical driving scenario are given.

1. Introduction

In 1991, the U.S. Congress through the Intermodal Surface Transportation Efficiency Act (ISTEA) initiated an Intelligent Transportation System (ITS) program to provide improved traffic safety and mobility, efficient transit operation and to minimize negative environmental impact [1]. The automated vehicle - highway system is expected to help conserve energy resources and to make more efficient use of existing transportation facilities. A common national system architecture for ITS is currently being developed [2, 3]. Some of the elements of the ITS architecture include in-vehicle navigation systems, Traffic Management Centers (TMC), which provide travel advisory, and other information to appropriately instrumented vehicles, probe vehicles, road sensors, real-time adaptive traffic control system, and communication systems.

The simulation of vehicle based surface transportation is broad and complex, thereby making it very difficult to reference all work done in this research area. For brevity, only closely related work is enumerated. Typical research on the development of large-scale traffic simulators is given in Refs. [4, 5]. Various car following models are summarized in Refs. [6, 7]. A discussion of Autonomous Intelligent Cruise Controls can be found in Ref. [8, 9]. At Argonne, an advanced simulator has been developed for instrumented smart vehicles with in-vehicle navigation units capable of optimal route planning and Traffic Management Center (TMC), Refs. [10 - 12].

An important aspect of traffic simulations is the study of human factors influencing the driver behavior [13]. Simulations allow the study of vehicle maneuvers in traffic flows based on situations involving vehicle/obstacle passing, lane change, distance following, and speed change with respect to the driver type, and environmental (weather and road) conditions.

When we began the development of an advanced simulator for highway traffic we looked at the simulator from three distinct angles, a traffic/system engineering, a computer science and a human factor study angle, thereby allowing us to address a large variety of simulation issues early on. For example, domain decomposition techniques as described in Ref. [14] can be easily applied, thus one can utilize parallel computing environments. In this paper the key components of the highway traffic simulator, i.e. a global and a local Expert Driver Model, a human factor study and a graphical user interface, are presented. Further, an Autonomous Intelligent Cruise Control which is based on a neural network controller is described and results for a typical driving scenario are given.

2. Expert Driver - Highway Traffic Simulator

The Highway traffic simulator includes two main components. The first component is a global Expert Driver Model (EDM) which simulates the vehicle traffic through the use of a Link Manager (LM). The Link Manager keeps track of information on all vehicles within its domain. It also communicates

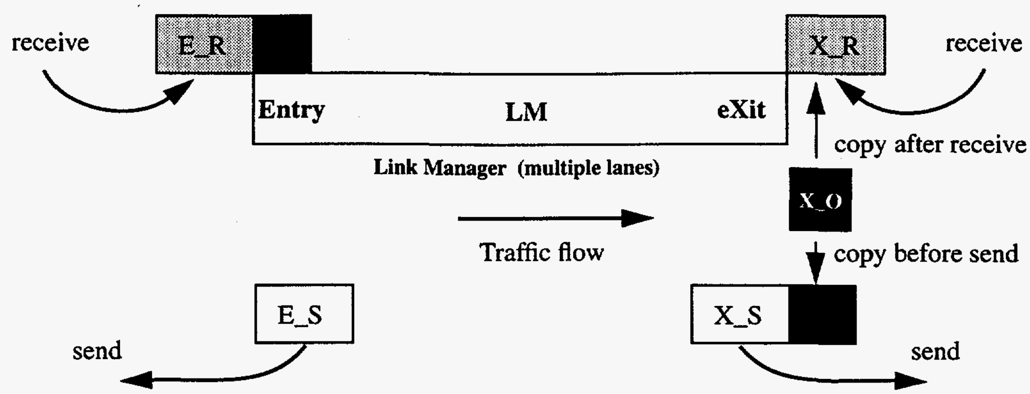

Figure 1 Schematic diagram of the Link Manager (LM) regions E_R, E_S, LM, X_S, X_R and X_O.

directly with adjacent link managers and with the vehicles under its jurisdiction. The second component is a local EDM which simulates vehicle-vehicle interaction in a multi-lane highway system. The local EDM has two sub-systems: the Driver Behavior Model which controls the vehicle's maneuvering and the Car Following Model, which controls the relative speed and distance between two vehicles. The vehicle maneuvering is based on information received from the Link Manager and/or from simulated on board instruments and human factor data.

2.1 Global Expert Driver Model (Link Manager)

Although for ordinary highway traffic the Link Manager (LM) is artificially introduced to facilitate the simulation, in the case of an Automated Highway System (AHS) the LM is the actual control environment. Many studies utilize a simple link management model, i.e. a single link in isolation without modeling entrance and exit regions. Although this is sufficient for many simulations the LM described in this paper is capable of interacting with surrounding/connecting links, thereby allowing for simulations of complex highway systems.

The basic multi lane-link is used to describe the design of the LM. However, link manager models for other link types of the highway system are being developed based on the same concepts. They include, among others, highway branching, merging, entrance and exit ramps.

A schematic diagram of a LM is shown in Figure 1. Figure 2 depicts the link connectivity of a basic multi lane link and the use of overlapping connectivity regions.

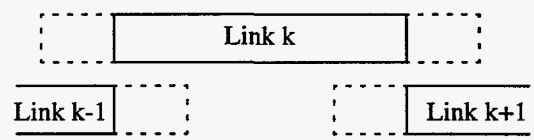

Figure 2 Link connectivity.

Only vehicles on the actual link are controlled by the LM. However, the LM has further knowledge of vehicles in the connectivity regions of adjacent links. This enables the LM to provide each vehicle on the link with the correct information regarding close by vehicles. The connectivity regions at the entrance (denoted by E) and exit (denoted by X) of the link are divided into receiving (E_R, X_R) and sending (E_S, X_S) zones. Here, the letters S and R denote sending and receiving, respectively. Furthermore, vehicles leaving the link during a simulation time step are collected into an overflow buffer (X_O). This overflow buffer is combined with the X_S region before sending to the adjacent LM. The length of the receiving and sending zones may differ for each link to accommodate the requirements of the connecting links.

Once the LM receives the information about the vehicles under its control and also those in the connecting zones, the local EDM is called to perform vehicle maneuvers for the next time step of the simulation.

Upon completion of the vehicle maneuvering phase, the global LM generates vehicle information for the connectivity regions at the entrance and exit of the link (E_S, X_S) as well as the overflow zone

(X_O). This information is transferred to adjacent links. The link manager receives similar information from connecting links. The simulation advances to the next time step where the whole process is then repeated. The design of the global EDM facilitates the use of parallel computers for the highway traffic simulation, since domain decomposition techniques as described in Ref. [14] can be applied in a straight forward fashion.

2.2 Local Expert Driver Model (Vehicle-Vehicle Interaction)

The local EDM determines the maneuvering behavior of all vehicles on a link taking vehicle-vehicle interaction into account. The maneuvers are further dependent on the road and weather conditions, the vehicle type and the type of driver. The details of these conditions are based on human factor studies, which are discussed below.

For the purpose of determining the vehicle-vehicle interaction, a vehicle cluster surrounding each vehicle on the link is created in the local EDM. For a divided highway consisting of three or more lanes in each direction the cluster contains up to 7 vehicles, as shown in Figure 3. For a two-lane highway,

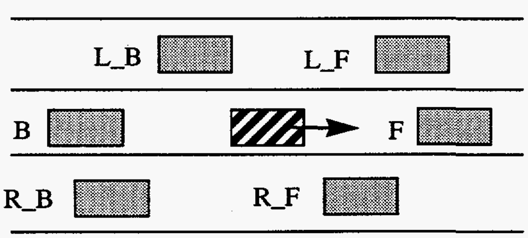

Figure 3 Seven vehicle cluster (R-right, L-left, F-front, B-back).

the cluster contains up to 5 vehicles. The vehicles are first sorted in a one- dimensional array (vector) according to the vehicles position on the link, followed by the creation of the cluster of vehicles around each vehicle on the link. The Driver Behavior Model is then called to advance each vehicle to the next time step.

In order to advance each vehicle to the next simulation time interval a decision has to be made by the Driver Behavior Model regarding the vehicle maneuver. The maneuver is based on the geometric structure of the vehicle-cluster and human factors information concerning type of vehicle, type of driver and road/weather conditions. The Driver Behavior Model selects one of the following choices: to change lane (right or left), to slow down, to speed up, or to proceed normally. If the decision is to follow the vehicle in front, the Car Following Model is called to provide the appropriate speed and acceleration information.

The Car Following Model utilizes a Neural Network Controller (NNC) to control the relative speed and distance between two adjacent vehicles in the same lane. This controller is used in two ways. The first is to simulate the actual human driver (Human Driver Model, HDM) and the other is to provide an autonomous intelligent cruise control (Automated Driver Model, ADM) as described in detail below.

2.3 Human Factor Study

The Human factor information incorporated into the local EDM is based on an exploratory experiment including actual observation and a literature study [15, 16].

The objective of the exploratory experiment was to develop parameters for speed change, vehicle/obstacle passing, lane change, and following distances. In the local EDM, these parameters are dependent on the following variables:

- type of driver (3): aggressive, nominal, 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)

The experiment was general in nature and involved the observation of vehicles during daytime on Chicago highways and inner roads.

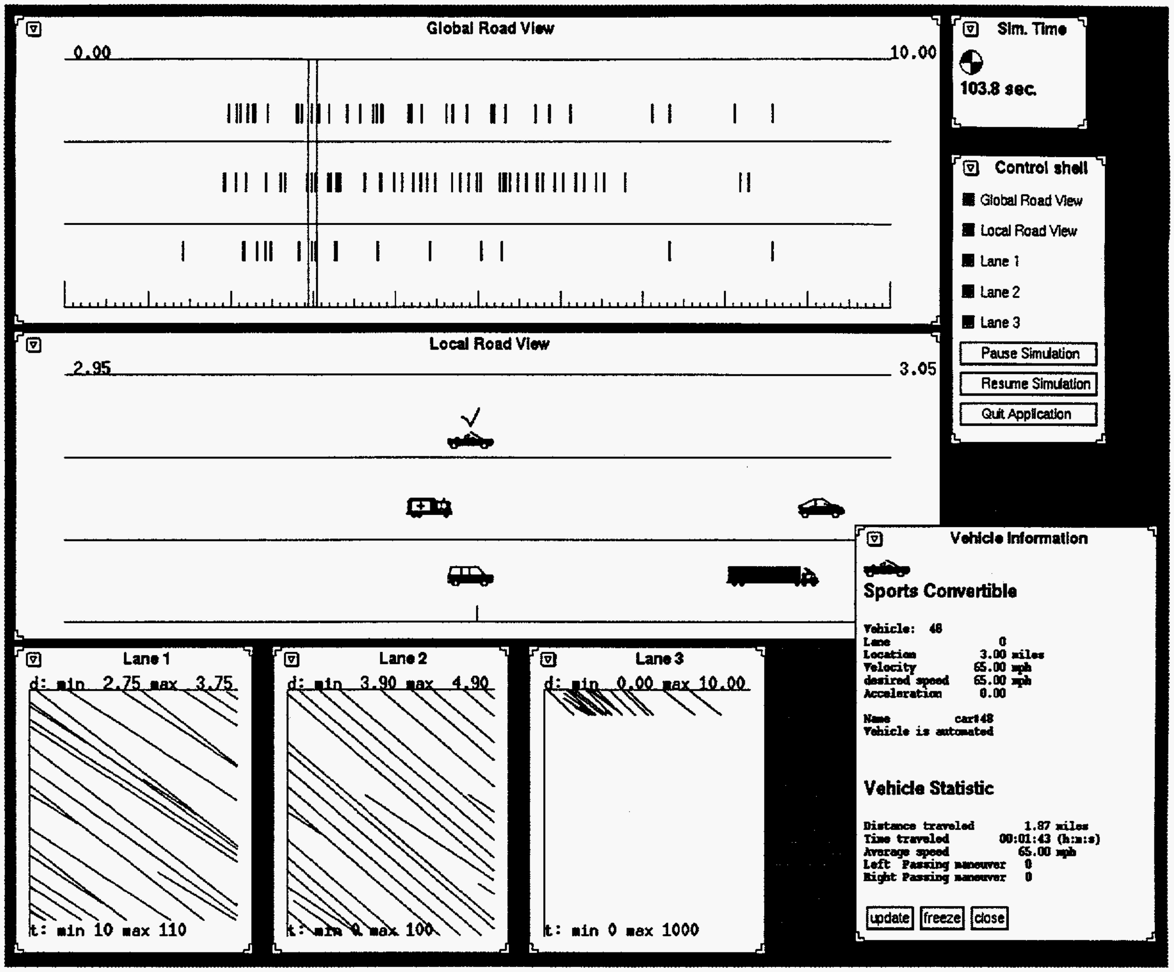

Figure 4 Graphic User Interface for the EDM Highway Simulator.

The experimenter paced a considerable number of cars over a period of time during clear, rainy, foggy, and windy conditions on roads that are smooth, rough, under construction (straight and curved) and tarred. The experimenter noted the approximate speed and distance (clear days only) between the vehicles and used these to define the specific parameters for the conditions of snow, freeze, and loose gravel, and to categorize the driver types. The data was stored in a three dimensional data matrix as an input data file for the local EDM. At present only conventional passenger vehicles have been studied, however, similar matrices will be created in the future to cover other kinds of vehicles (e.g. truck, emergency vehicle, bus, etc.).

In the above study, distance measurements were recorded in terms of car length. Current studies use time and vehicle speed. Using time and speed to represent distance will simplify the implementation of a driver model which is based on artificial neural network techniques.

Undoubtedly for a more realistic and statistical sound human factor model, more actual data is required. This can be accomplished by using an instrumented vehicle and human drivers in a field research laboratory, as well as previously collected data by other research groups. However, at this stage of the local EDM development, the observed data used to establish the parameters suffices.

2.4 Graphic User Interface (GUI)

A graphical user interface has been developed for the Expert Driver Model. A gray-scale screen copy of the color display is shown in Figure 4. The GUI is written in C and is based on X11/Motif.

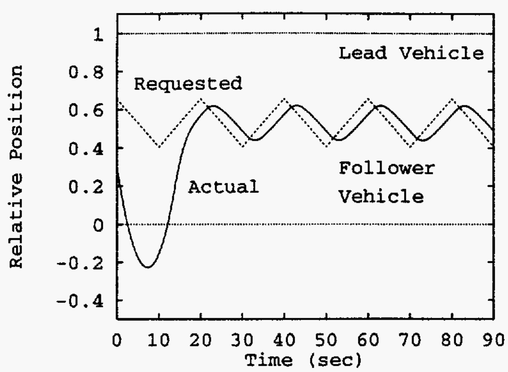

Figure 5 a Relative position.

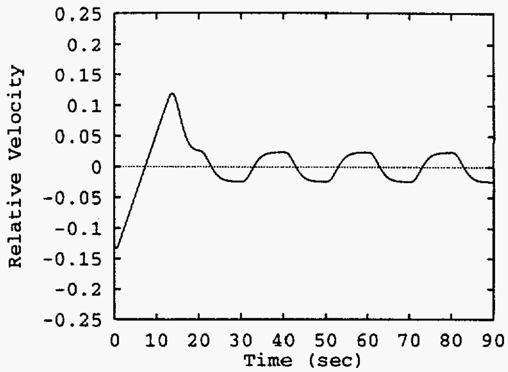

Figure 5 b Relative velocity.

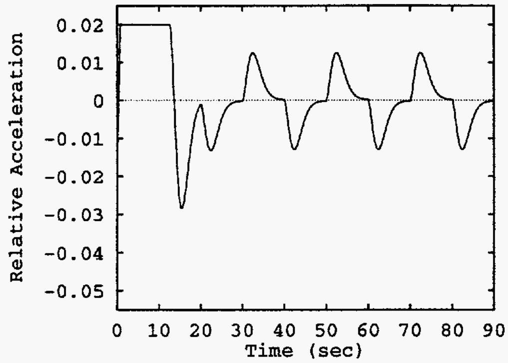

Figure 5 c Relative acceleration.

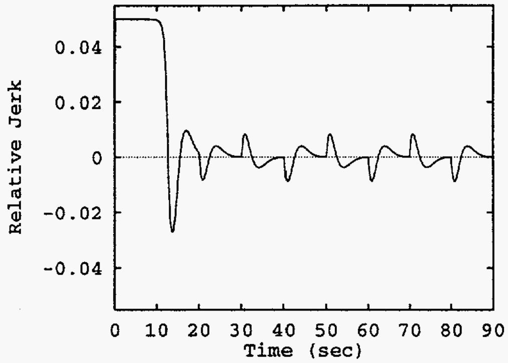

Figure 5 d Control action (jerk).

Several windows are shown here. The top window gives a global view of the vehicles on a single link. Below this window is a detailed view of the vehicles on a

0.1 mile stretch of the highway. This localized region can be selected by clicking on any region in the global view of the road. The selected region is indicated by two vertical lines in the top window.

With a click of a mouse button one is able to retrieve information and statistical data for any vehicle currently visible in the local road display. The selected vehicle is then marked and a window appears in the lower right corner displaying vehicle identification number, location, speed, lane, etc. A location-time diagram for each of the three lanes is displayed along the bottom of the screen. A zooming capability allows for the detailed study of car following and passing maneuvers.

Further, any window of the GUI can be resized and individually closed and opened. Two additional windows on the right side of Figure 4 display the simulation time and contain display control buttons.

3. Autonomous Intelligent Cruise Control

The AICC is an assisting system capable of controlling the relative speed and distance between two adjacent vehicles in the same lane. In the model the leader moves independently of the follower. The AICC is attached to the follower which can control its velocity and position with respect to the leader. The resulting control system provides the appropriate rate of change of acceleration, i.e. the jerk, of the follower vehicle in order to maintain a requested longitudinal distance between the two vehicles. In general this longitudinal distance is not a constant parameter but can be set either arbitrarily or according to a certain criterion (e.g., to keep a constant time headway).

Due to space limitations, the neural network design, its training and the underlying vehicle dynamics model can not be given here. The interested reader is referred to [17] for an in-depth description of the AICC.

As an example of AICC results, a study of two proceeding vehicles is presented. The initial conditions of the two vehicles are as follows: the absolute velocities of the follower and lead vehicle are 25.0m/s (90 km/hr) and 27.8m/s (100 km/hr), respectively; the accelerations of the follower and leader are initially zero and +2.0m/s2, respectively and the initial distance between them is assumed to be 70 meters. During the simulation the acceleration of the leader alternates between +2.0m/s2 and -2m/s2 every 10 seconds. The NNC controls the follower in order to maintain a constant time headway of 1.25 seconds behind the lead vehicle.

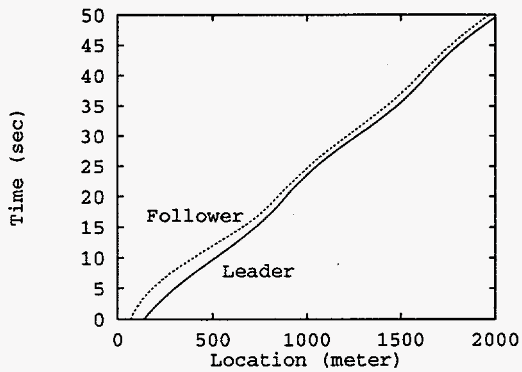

Figure 6 Location versus time diagram.

The normalized relative position, velocity and acceleration of the follower with respect to the leader is shown in Figures 5(a-c), and the control action (jerk) provided by the NNC as a function of time is given in Figure 5(d). For simplicity, the coordinates in the relative reference system are normalized such that 1 unit of length equals 100 meters. In addition, the position of the lead vehicle is always assumed to be at 1. As discussed previously, the velocity of the lead vehicle oscillates during the course of the simulation and the requested distance between both vehicles varies in time. This is illustrated with the zigzag dotted line in Figure 5(a). The location versus time diagram for the leader and follower is given in the Figure 6, which shows the wavy path of the leader due to its cyclically changing velocity and the path of the follower as a result of the AICC.

3.1 Graphical Display of the AICC Simulator

As with the Expert Driver Model, an AICC-simulator with color graphic displays has been developed to facilitate the testing and evaluation of the AICC system. The simulator provides animated graphics showing the motion of two vehicles on a road segment in three different displays. Two windows in the simulator provide the location of the vehicles on the road. One of these windows shows the relative location of the vehicles from the point of view of the follower (sliding road view) and the other shows the actual position of the vehicles on the road. A third window contains a 3-D view of the road as seen by the follower. The information regarding the relative position, velocity, acceleration and jerk of the follower vehicle as a function of time is also displayed graphically as the simulation progresses.

4. Conclusions

A computer model has been developed to simulate highway traffic for various degrees of automation with a high level of fidelity in regard to driver control and vehicle characteristics. The model simulates vehicle maneuvering in a multi-lane highway traffic system and allows the use of an Automated Intelligent Cruise Control. An Expert Driver Model of instrumented vehicles with an in-vehicle navigation unit has also been incorporated.

The highway traffic simulation includes realistic modeling of variations to the posted driving speed which are based on human factor studies that take into consideration weather and road conditions, driver's personality and behavior, vehicle type, and safe-passing zones. In order to simulate realistic lane change behavior, the model searches for and identifies the cluster of vehicles surrounding each vehicle before performing any maneuvering decisions.

The simulator is designed in such a way that each vehicle is represented by an autonomous simulation module, while interaction of the vehicle with its surrounding is controlled by an in-vehicle sensor system and/or by a link manager process. A graphical user interface has been developed to study highway traffic flow under various conditions.

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