For the graduate category

A Microscopic Traffic Simulator for Evaluation of Intelligent Transportation Systems

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Abstract

This paper develops a microscopic traffic simulator capable of evaluating Intelligent Transportation Systems (ITS) and various traffic control and management strategies. The simulator can simulate the operations of vehicles on general traffic networks including freeways, arterials, and urban streets. It represents a wide range of ITS designs, models the movement of individual vehicles in the network including the response of drivers to real-time traffic information and controls and incorporates the dynamic interaction between ITS or various traffic control and management strategies and the drivers on the network. This simulator is composed of three modules: traffic flow module, traffic control and management module, and traffic surveillance module. It is implemented in Visual C++ using object-oriented method and visualization technology. A graphical user interface (GUI) allows users to visualize the simulation process, including animation of vehicle movements, measurement of surveillance sensors, state of traffic signals and signs, etc. The simulator was validated through three case studies. The preliminary results support the value of the simulator as a potential tool for evaluation of ITS and various traffic control and management strategies.

1. INTRODUCTION

With the advent of globalization, the need to physically move goods and people from one place to another has never been greater. Road traffic congestion is becoming a more and more significant problem in modern society. It has multiple impacts. Traffic congestion increases transportation costs and reduces quality of life, productivity and safety. It also deteriorates environmental quality by more tail-pipe emissions and noise. Traffic congestion on the freeways and highways of the United States continues to worsen.

Due to constraints on the availability of land and financial resources along with intense political and environmental concern, building new roads as the remedy to mitigate congestion is unable to keep up with the spiraling growth of traffic congestion and becoming infeasible. One attractive alternative remedial measure is the development and deployment of Intelligent Transportation Systems (ITS). ITS are transportation systems which apply emerging Information Technology (IT) to address and alleviate traffic congestion problems. ITS have the potential to improve traffic conditions and reduce travel delays by facilitating better management and utilization of available capacity of existing infrastructure(Lieu 2003). Advanced Traffic Management System (ATMS) and Advanced Traveler Information System (ATIS) are two typical ITS. ATMS refers to traffic control system which imposes constraints such as traffic signal lights, ramp metering, speed limit signs and lane use signs on traffic flows. ATIS refers to information system that provides traffic information and travel recommendations to travelers through means such as radio broadcast, internet or on-board navigation systems and variable message signs (VMS) so that travelers can make pre-trip travel decisions such as destination, departure time, mode and route and en-route switch decision.

While developing new ITS or traffic control and management strategies is becoming easier, these systems or strategies do not always result in expected or improved performance(Gartner, Stamatiadis et al. 1995). Evaluation is therefore indispensable for assessing the performance of alternative designs and answering various “what if” questions.

There are two approaches which can be used in evaluation of ITS or traffic control and management strategies. One is field test and the other is simulation. Field tests tend to be extremely expensive. In addition, test results are heavily dependent on many uncontrollable elements of test environment, such as weather conditions, travel demand or incidents(Yang 1997). Simulation evaluation allows for studying complex interactions among various components of a traffic system under a controllable environment at low cost(Yang, Koutsopoulos et al. 2000). Simulation is becoming a popular evaluation tool in traffic research community. While many traffic simulation models have been developed, they are lacking in capability of evaluating ITS, particularly ATMS and ATIS, and traffic control and management strategies. Examples are DynaMIT(Moshe 1996), DYNASMART(Jayakrishnan, Mahmassani et al. 1994), INTEGRATION(Van Aerde and Yagar 1988).

To meet this need, a microscopic traffic simulator is developed for testing and evaluating designs of ITS and traffic control and management strategies on general networks including freeways, arterial, and urban streets in this paper. This is a computer software system.

The rest of this paper is organized as follows. We first present the framework of this microscopic traffic simulator. Design and implementation of this simulator is presented next, followed by preliminary validation results.

2. FRAMEWORK

Figure 1 illustrates the overall evaluation framework of ITS or traffic control and management strategies. To evaluate these systems or strategies, we need to create scenarios representing the operational environment under which these systems or strategies will be evaluated. Scenarios are usually determined by the following factors(Yang 1997): (1) traffic demand; (2) events, such as incidents and surveillance and control device failures; and (3) driver behavior and vehicle characteristics. In the evaluation process, a set of candidate designs are usually tested over a set of scenarios and compared against a base case. The initial scenarios represent expected conditions under which the system operates. The simulated performance measures quantify the effectiveness of the system and illuminates potential design shortfalls. This information is used to formulate additional scenarios in order to further challenge the system and test its robustness. In this way the scenarios under which each design is tested are generated iteratively. These results are then analyzed to suggest modifications to improve the original design.

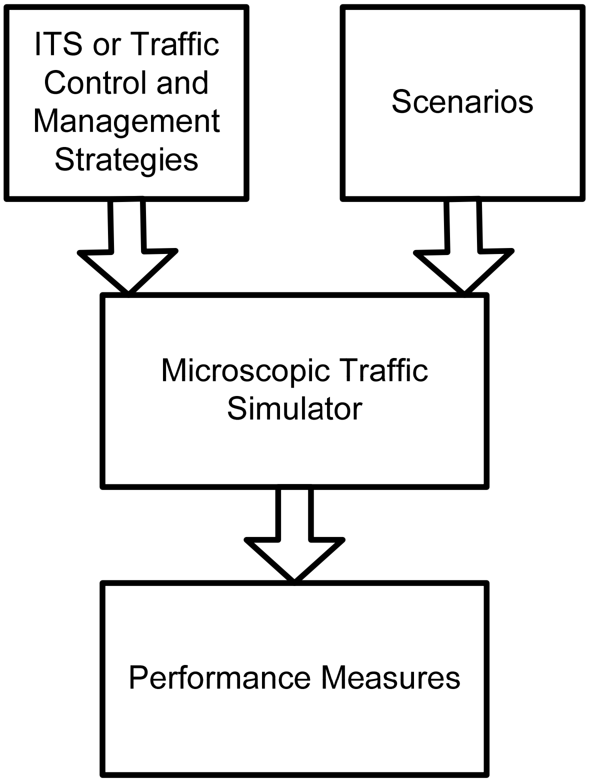

Figure 1: Overall Evaluation Framework

This microscopic traffic simulator consists of three modules, as shown in Figure 2:

1) Traffic flow module
2) Traffic control and management module

3) Traffic surveillance module

Traffic flow module models traffic flows in the network at the vehicle level, including driver behavior. Traffic control and management module models ITS or traffic control and management strategies under evaluation. These strategies are fed into traffic flow module and affect the behavior of individual drivers and hence traffic flow characteristics. The changes in traffic flows are in turn measured by traffic surveillance module, which provides the traffic control and management module the traffic information necessay to refine traffic control and management strategies.

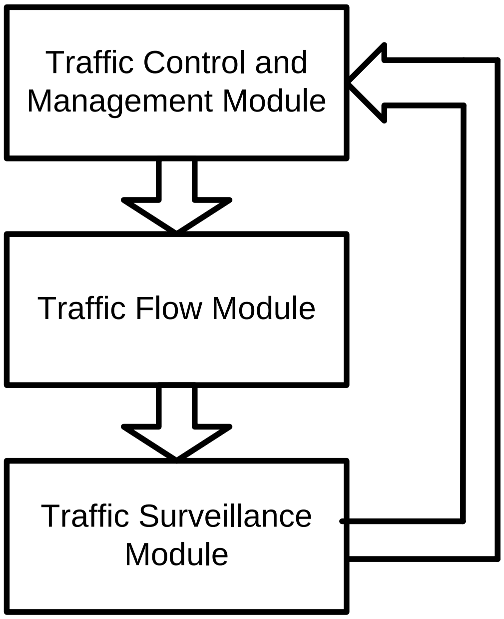

Figure 2: Module Structure

3. SYSTEM DESIGN

In this section we describe the system design of this microscopic traffic simulator. This simulator uses a time-based simulation logic. During each time interval, individual vehicles are moved according to car following, lane changing logic; speeds and positions of vehicles and the records of traffic surveillance system are updated.

3.1. Road Network

The first step of system design is to create road network. We developed a graphical road network editor (RNE) to create various network objects including nodes, links, segments, lance connections and toll-plaza, sensors and traffic signals in the simulator. The network database includes descriptions of all network objects, lane connections, lane-use privileges such as electronic toll collection (ETC) and high-occupancy-vehicle (HOV) operation, regulation of turning movements at intersections, traffic sensors, control devices, and toll plazas.

The simulator represents road networks with nodes, links, segments, and lanes(MIT 2001). A node is either an intersection of several roadways or an origin and/or destination where traffic flows enter or leave the simulated network. Each node is represented by its type (e.g. intersection, origin/ destination), a unique identification number, and an optional name. Links are directional roadways that connect nodes. Each link consists of one or more segments, whose geometries are represented by arcs. An arc is described by the coordinates of its two end points and a bulge. If the bulge is zero, the arc is simply a straight line. Each link is characterized by its type (freeway, ramp, urban street, tunnels, etc.), an identification number, starting and end nodes, and the segments it contains. An inbound link and an outbound link of a node are connected if there exists one lane connection between the two. Turning restrictions from one link to another are specified by a turning prohibition table. Segments are road sections with uniform geometric characteristics such as number of lanes, grade, curvature, design speed, etc. Each segment is characterized by its speed limit, design speed, grade, geometry, a unique identification code and the lanes it consists of. The simulator represents the network at the lane level. Each lane is described by two data items: (i) lane code, a unique identification code; and (ii) a lane change regulation and lane-use privilege code. Lane change regulations determine whether a lane change between adjacent lanes is allowed. Lane use privilege specifies the classes of vehicles that are or are not allowed to use the lane. For example, a lane may be assigned to high occupancy vehicles (HOV), electronic toll collection (ETC) vehicles, and/or commercial vehicles only. It may also exclude the use of the lane by particular types of vehicles such as over-height vehicles, trucks, etc. The lane-use privilege code for a particular lane can be any consistent combination of predefined basic types. Each lane can be connected to one or more upstream and downstream lanes (e.g. at toll plaza, merging, and fork area) or has no lane connection at all (e.g. lane drop or network boundary). A lane connection table, which contains a pairwise list of lane codes, is used to represent the connections between upstream and downstream lanes.

A variety of surveillance systems can be represented in the simulator, including point (such as loop detectors), point-to-point, and areawide sensors. Sensors are represented by their technical capabilities such as operational status and measurement error.

The simulator supports the simulation of a wide range of traffic control and route guidance devices, including intersection traffic signals (TS), yield and stop signs, ramp meters, lane use signs (LUS), variable speed limit signs (VSLS), portal signals at tunnel entrances (PS), variable message signs (VMS), and in-vehicle route guidance devices. Traffic control devices also have visibility parameters that determine where vehicles may start responding to them.

An incident may completely block one or more lanes or produce a rubbernecking effect in which vehicles slow to a particular speed, or it may have both effects. Incidents are also characterized by their duration (clearance time), which may depend on the detection delay and response plans of the traffic control and management module.

Figure 3 shows El Paso’s road network created by our RNE.

3.2. Simulation Process

The simulation process of this simulator is a time-based iterative procedure(Yang, Koutsopoulos et al. 2000). The simulation is initialized by loading simulation parameters, road network and scenario definition. After initialization, an iterative procedure begins. During each iteration, the following tasks must be performed:

1) Update the state of traffic signals, signs, and incidents;
2) Update routing tables and calculate shortest paths to all destinations;

3) Read new origin-destination (OD) trip tables and generate corresponding virtual vehicle queues at the origin nodes;
4) Load vehicles from the virtual queues into the network;
5) Update vehicles acceleration rates and make necessary lane changes;
6) Advance vehicles to new positions and update their speeds. If a vehicle activates a sensor, the corresponding measures (speed, occupancy, etc.) are recorded by the surveillance system module. At the end of a lane, a vehicle is either removed from the network (if it arrives at its destination) or handed to the downstream lane;
7) Update the display if the graphical user interface (GUI) is enabled;
8) Calculate the MOE and/or send network states to external MOE or GUI modules;
9) Update the simulation clock and move to next iteration.

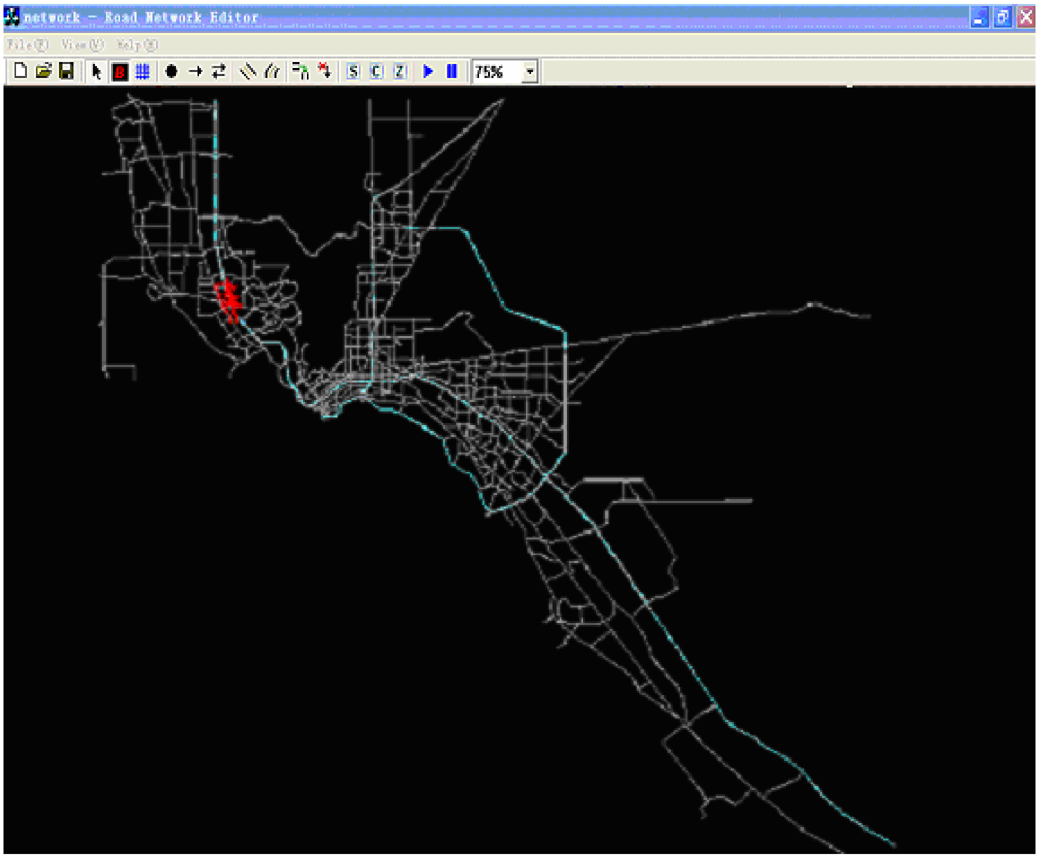

Figure 3: El Paso's Road Network Created by RNE

In general, the simulator uses a time-based simulation approach in processing the vehicle movements. The car-following, lane-changing, and event and signal response functions are invoked for each vehicle at a specified interval (e.g. 1 second). Speeds and positions of the vehicles and states of surveillance sensors are updated at a higher frequency specified by the user (e.g. 1/10 or 1/2 second). This step size is subsequently used to advance the simulation clock. The step size, which is drawn from a given distribution and randomly assigned to individual vehicles, has to be greater than or equal to the step size and a modulus. The actual step size applied for a particular vehicle at a given time may vary (but must be a modulus) during the simulation as drivers' reaction times differ in some special conditions (e.g. too close to the leading vehicle, making a lane change, or delayed at too booth and red signal, etc.).

3.3. Traffic Control and Management Module

The module simulates the operations of a wide range of traffic control and management devices: Intersection controls: traffic signals and yield and stop signs; Ramp controls: ramp metering and speed limit signs; and Mainline controls: LUS, VSLS, VMS, portal signals at tunnel entrances. These devices can be controlled by pretimed, traffic-adaptive, or metering controllers. A controller can switch from one type to another on the basis of some predefined logic. Several control strategies that cover the most common control types are already implemented. These preprogrammed strategies can be activated through parameters specified in input files.

The control logic for a pretimed controller is specified through input files by an offset and a timing table, which consists of a set of phases and control intervals. A control interval represents a period of time during which states of all signals remain constant. The data items describing a control interval are its duration and a vector of signal states, which specify the right-of-way for various turning movements.

Adaptive controllers use real-time data from surveillance detectors and prespecified control laws. Depending on the particular system to be evaluated, its control logic may be a special case of the general adaptive controller already implemented in the module and activated through a data file or coded as a new customized controller module to interface with the module. The modular design and object-oriented implementation facilitate the addition of new types of controllers into the system. The default adaptive controller is described by three sets of data records: signals, phases, and detectors. The signal records prescribe the maximum red times and the phase to be called next in the event that continuous red time for that signal has reached its maximum value. The phase records represent the timing data and control sequence as in pretimed controllers. However, for adaptive controllers, a phase can be extendible, callable, or both. A phase is extendible if its green interval can be extended when detector data satisfy certain criteria and no conflicting movement has reached its maximum red time. A phase is callable if, after completion of the current phase, signal operations can be shortcut to this phase before the subsequent phases in the cycle have been completed. The detector records specify the logic for extending the current phase and calling a new phase. A controller may contain any number of detector records, each corresponding to a single detector. These records contain flags that specify the conditions for extending or calling a particular phase. Detector records are organized in descending order according to their priorities.

Ramp and mainline metering can be represented by either pretimed or adaptive controllers. The implemented metering logic uses desirable network states, such as occupancy at given locations, to compute the timing table. The desirable network state can either be predetermined(Papageorgiou, Hadj-Salem et al. 1991) or be set dynamically by external control modules(Chen 1996). Thus, the TMS is capable of simulating systems with a two-level hierarchical control logic in which (a) a systemwide optimization model calculates the desired network state and (b) a local closed-loop feedback controller adjusts the metering rate in order to minimize the difference between actual and desired network states. Alternatively, the metering can be based on changes in the inflows and outflows at given locations(Hasan 1999).

Several freeway incident detection algorithms and a rule-based incident management scheme that influences the state of lane control devices are implemented in the module. These algorithms can also be combined to provide a higher detection rate with fewer false alarms. Incident management is represented by response plans, which determine the status of the control devices in the network. A response plan is activated after the incident is detected and confirmed. Each response plan consists of one or more response phases, characterized by an activation delay and a set of actions to be taken in various situations. The final phase of a response plan, the clearance phase, defines the actions to be taken after the incident is cleared (usually restoration of the devices to their default states).

3.4. Traffic Flow Module

The simulator maintains two sets of time-variant travel time information: historical and real-time link travel times. Historical travel times are used to assign vehicles to their habitual routes. Real-time travel times are updated periodically or when information is received from the traffic control and management module. The updated travel times are transmitted to the vehicles equipped with in-vehicle route guidance devices and used to update their paths. They are also used to update the status of VMS. Any vehicle may respond to VMS according to a prespecified compliance rate. Modified logit-based route choice models(Cascetta, Nuzzolo et al. 1996; Yang 1997) are used to capture drivers' route choice decisions and response to traffic information.

The simulator moves individual vehicles according to acceleration, lanechanging, and merging logic embedded in the simulator.

A vehicle accelerates (decelerates) in order to (a) react to the vehicles ahead, (b) perform a lane-changing or merging maneuver, (c) respond to events (e.g., red signals and incidents), and (d) achieve its desired speed. The most constraining of these situations determines the acceleration (deceleration) rate to be implemented in the next simulation cycle. On the basis of the time headway from its leader, a vehicle can be in a free-flowing, car-following(Herman, E.W.Montroll et al. 1959; Herman and Rothery 1961; Wicks 1977; Yang 1997; Ahmed 1999), or emergency-decelerating regime. The acceleration in the free-flowing regime is a function of the vehicle's desired speed, whereas in the car-following and emergency decelerating regimes, the acceleration is calculated on the basis of headway and speeds of the vehicles concerned.

The lane-changing model(Gipps 1986; Ahmed, Ben-Akiva et al. 1996; Ahmed 1999) implemented in three steps: (a) checking if a change is necessary and defining the type of the change, (b) selecting the desired lane, and (c) executing the lane change if the gap is acceptable. Lane changes are mandatory or discretionary. Mandatory lane changing occurs when drivers have to change lanes in order to connect to the next link on their path, bypass a lane blockage downstream, avoid using a restricted lane, or respond to VMS or LUS. A discretionary lane change refers to cases in which drivers change lanes in order to improve their driving conditions. The decision to seek a discretionary lane change depends on the vehicle's speed, the difference in traffic conditions between the current and adjacent lanes, driver's desired speed, and other factors. Once a driver has decided to change lanes, he examines the lead and lag gaps in the target lane to determine whether the desired lane change can be executed. If both the lead and lag gaps are acceptable, the desired lane change is executed instantaneously. The minimum acceptable gaps take into account the speed of the subject vehicle, speed of the lead and lag vehicles, and whether the lane change is mandatory or discretionary.

When two or more upstream lanes are connected to a single downstream lane, a merging area is defined for the transition. Merging is classified into priority merging and nonpriority merging. Priority merging includes merging from ramps to freeways and from minor streets to major streets. Nonpriority merging occurs, for example, downstream of toll plazas.

In heavily congested traffic, gaps for merging and lane changing are difficult to find. Courtesy yielding refers to the cases in which a driver decelerates to make space for another vehicle switching into his lane. Forced merging refers to the cases in which the existing gap is not acceptable but the driver creates the gap by forcing another vehicle to yield. The probability of courtesy yielding and forced merging is a function of traffic conditions and characteristics of the subject drivers. When a driver has decided to yield, his state is maintained until the merge or lane change is completed or is canceled after a maximum amount of time has elapsed.

3.5. Input

The most important input of the simulator is Origin-Destination (OD) tables which represent time-dependent travel demands for every OD pair. The travel demand for each OD pair is characterized by the following data items: an average departure rate and its standard deviation, a distribution factor, and a list of paths that connects this OD pair. The last 3 data items are optional and default values are supplied. OD tables can be specified individually for each vehicle type, or alternatively, the simulator can randomly assign a type to the vehicles on the basis of given percentage of each vehicle type. Vehicle type is a combination of vehicle class (e.g., motorcycle, automobile, truck, bus), lane-use privilege (e.g., HOV and ETC), access to information (e.g., informed and uninformed), and driver behavior (e.g., aggressiveness and compliance). A vehicle trip table file can also be used. It contains a list of scheduled vehicle departure times and the corresponding origin, destination, and optionally, type and predetermined path.

When a vehicle enters the network, a set of vehicles and driver characteristics are assigned to it. A pretrip path, if not uniquely specified in the input file, will be calculated on the basis of route choice models. Each vehicle enters the network from the upstream end of the first link on its path. Its initial position and speed are determined by the simulation step size, the driver's path and desired speed, and the traffic conditions in the loading segment. If necessary space is not available, the vehicle is stored in a first-in-first-out (FIFO) queue and waits to enter the netwok during subsequent time intervals.

3.6. Output

The output from the simulator can be classified into three categories: sensor readings, Measures of Effectiveness (MOE), and animation graphics. Due to the stochastic nature of the simulation, multiple simulation runs should be conducted for each scenario to obtain statistically significant evaluation results.

Point sensor data, such as traffic counts, occupancies, and speeds, are reported to the traffic control and management module at a given frequency and logged into output files. Sensor identification and vehicle information such as vehicle identification and speed are reported each time a probe vehicle passes a point-to-point sensor.

Detailed data on vehicle trajectory and trip information can be recorded during the simulation. Traffic volumes and average link and path travel times at various levels of resolution can also be collected. Furthermore, snapshots of queue lengths at selected locations can be reported at a user-selected frequency. By using appropriate models, MOEs concerning fuel consumption, emissions, safety, and so forth can be developed.

The simulator includes a Graphical User Interface (GUI) for visualization of the simulation input and output: The road network is shown color coded by direction, facility type, density, speed, or flow. Dynamic information (e.g., speed) is updated at a user-specified frequency; Sensor measurements (e.g., counts) are displayed and refreshed; The status of traffic control devices is displayed by dedicated symbols; Vehicle movements are animated, and information such as vehicle type and car-following and lane-changing status are selectively displayed.

Figure 4 shows a GUI of the simulator.

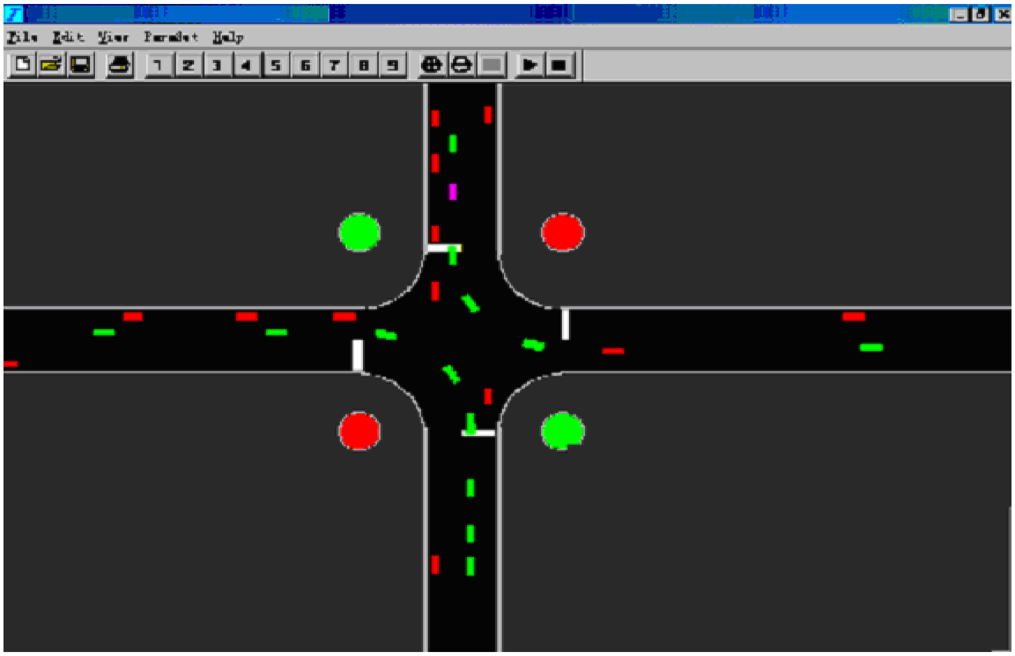

Figure 4: Graphical User Interface

4. SOFTWARE IMPLEMENTATION

In the simulator, the object-oriented methodology is applied to divide the whole system into three separate modules, encapsulate their inner behaviors, and provide an outer standard interface. In each module, the common characteristics of all sub modules are extracted as the base classes, and the concrete characteristics are described by their deriving classes. Furthermore, the simulator is set up with the object-oriented software design technology.

Also, the visualization technology is applied to give the dynamic display of simulation evolution and the characteristics in simulation. It can enhance debugging ability of the simulator, so as to reduce the modeling time. The application of visualization technology can also give us a conceptual understanding about system dynamics, and excellent graphics can give more confident evidence than printed data(Lin and Cai 2002). In the simulator, the simulation clock is 0.1s, i.e., two times faster than the machine clock. Therefore, the simulation step is fixed.

The simulator is developed with Visual C++. It consists of frame class (CMainFrame), document class (CTrafficSimDoc), application class (CTrafficSimApp), and view class (CTrafficSimView), also including some self-defined classes. The first four classes are common in most general MFC programs. Programmers only need to revise them to adapt their special applications. Other self-defined classes mainly include link class (CLink), node class (CMainNode), OD class (COD), urban traffic map class (CMap),vehicle class (CVehicle), and so on. They are used in CTrafficSimDoc class and CTrafficSimView class.

CLink class: An object of CLink describes a link in a traffic network. Each link may include multiple lanes. Each lane is described by a data list that is a kind of data structure. The pointers to vehicles in a lane are stored in the data list. Updating the data members of velocity, acceleration, position of vehicles can complete the vehicle movement in a lane. The lane change of vehicles can be described as the insertion and deletion of lane data list.

CMainNode class: An object of CMainNode class represents a node that is an intersection in the traffic network. Data members include ID, name, coordinates, the IDs of upstream and downstream links, etc.

COD class: An object of the class represents a pair of OD. Data members include origin ID, destination ID, vehicles' departing time intervals ordered by time, all links' IDs along the shortest path between the origin and destination, etc.

CMap class: An object of CMap class is used to draw, move, enlarge or reduce the traffic map that is the background of vehicles' animation.

CVehicle class: An object of CVehicle class represents a vehicle in the network. Data members include ID, origin and destination IDs, current link and lane IDs, next link ID on its path, class ID (such as car, bus, etc.), geometrical characteristics (length, width, height), position coordinates, moving direction, current velocity and acceleration, motion parameters (such as maximum acceleration, expected speed, etc.). Method members include updating acceleration, updating velocity, moving vehicle, and drawing vehicle, etc.

CTrafficSimDoc: CTrafficSimDoc object is used to store and process the data generated in a simulation process. With the classes self-defined above, all the simulation computations are performed in an object of this class. The main data members include all the nodes objects, all the links objects, all the OD objects, the traffic network database object, the simulation parameters (step, start and end time of simulation, and current simulation time, etc.), and data files objects.

CTrafficSimView class: An object of CTrafficSimView is used to display the data in CTrafficSimDoc objects, such as vehicle animation, and communicate with the operators. The main data members of this class include the pointer to CTrafficSimDoc object, CMap object, position coordinates and display scalar of traffic map, and human-machine interface objects (e.g. dialogue boxes about traffic conditions),etc.

5. CASE STUDIES

In this section, we present some preliminary results from three case studies to validate the performance of this microscopic traffic simulator.

5.1. Hollywood Freeway

The network used in this case study is the southbound direction of U.S. Highway 101 (Hollywood Freeway) in Los Angeles, California, as shown in Figure 5. The site was approximately 2,100 feet in length, with five mainline lanes throughout the section. An auxiliary lane is present through a portion of the corridor between the on-ramp at Ventura Boulevard and the off-ramp at Cahuenga Boulevard. The merge/weave section includes the Ventura Boulevard on-ramp and the Cahuenga Boulevard off-ramp connected by an auxiliary lane.

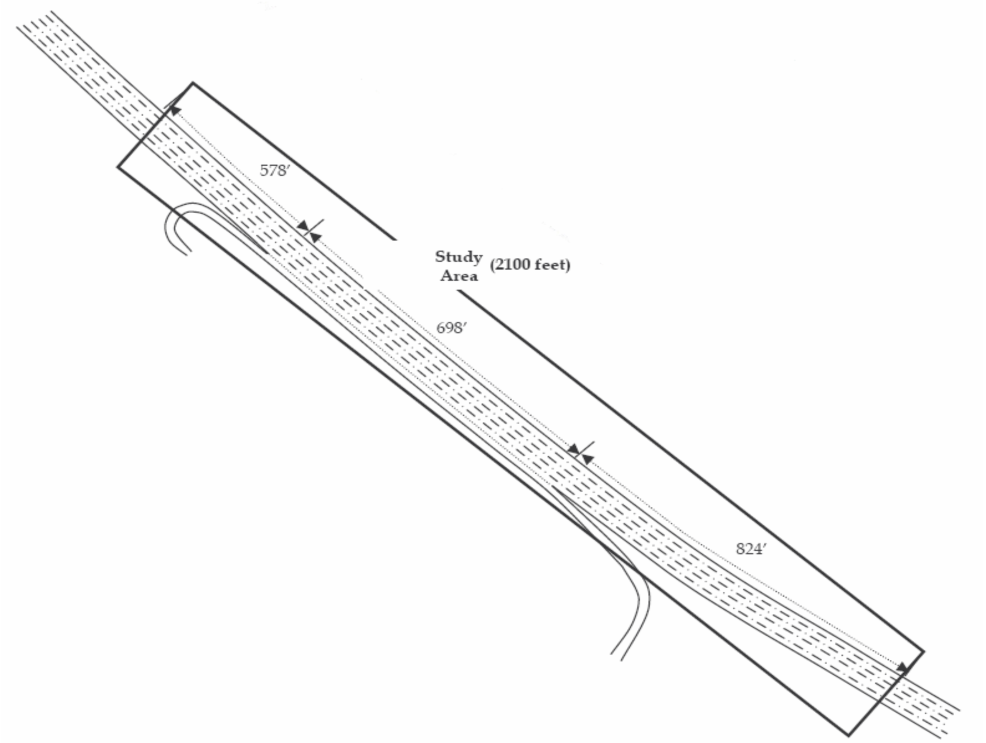

Figure 5: U.S. Highway 101 (Hollywood Freeway)

The Next Generation Simulation (NGSIM) team from the Federal Highway Administration (FHWA) colleted the field data on the section between 7:50 a.m. and 8:35 a.m. on June 15, 2005. According the data analysis report provided by NGSIM(NGSIM 2006), entering flow and vehicle type are shown in

Table 1 and Table 2 separately.

Table 1: Entering Flow

Entering Flow (vehicles)	Time Period (P.M.)								
	7:50-7:55	7:55-8:00	8:00-8:05	8:05-8:10	8:10-8:15	8:15-8:20	8:20-8:25	8:25-8:30	8:30-8:35
On-Ramp	53	41	39	45	44	41	46	52	47
Freeway Lanes	717	710	578	652	652	547	607	562	566

Table 2: Vehicle Type

Vehicle Type	Percentage		
	7:50-8:05	8:05-8:20	8:20-8:35
Motorcycle	1.4%	0.5%	0.3%
Automobile	96.2%	97.3%	97.6%
Truck and Bus	2.4%	2.2%	2.1%

We created the same road network and specified the same entering flow and vehicle type in our simulator. From the simulation outputs, we calculated the average speed. Comparison with actual average speeds is summarized in Table 3. We found that the maximum difference between actual average speeds and simulated average speeds is less than 3%.

Table 3: Comparison of Average Speeds

	Average Speed (mph)		
	7:50-8:05	8:05-8:20	8:20-8:35
Actual Results	25.66	21.59	17.96
Simulation Results	25.06	21.08	18.42
Difference(%)	-2.3%	-2.4%	2.6%

Fundamental diagram, i.e., flow-density relationship, is a very important tool to verify the effectiveness of microscopic traffic simulation model because it capture constraints on a traffic system such as road characteristics, vehicle type, driver's behavior, weather conditions, and traffic rules. The standard fundamental diagram has a parabolic or triangular form.

From the simulation results we get the fundamental diagram as shown in Figure 6. Obviously the figure is close enough to parabolic or triangular in shape though it exhibits some scatter. This validates further the effectiveness of our simulator.

5.2. Flow Distribution of Merging Traffic

When two upstream branches merge into one downstream roadway, flow distribution will follow the established rule: If the total demand of both upstream branches is less than the capacity of the downstream roadway, the ratio of the outflow from one upstream branch to that from the other branch is equal to the ratio of the same branch's demand to the other branch's demand.

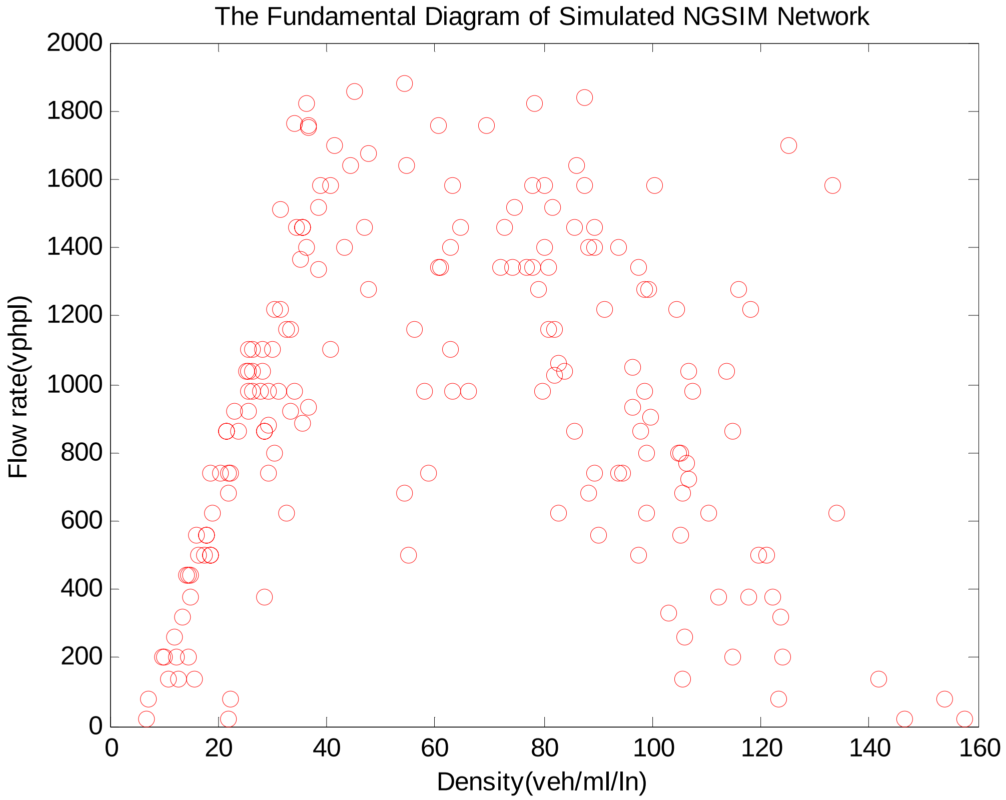

Figure 6: The Fundamental Diagram of Simulated NGSIM Network

Figure 7 shows a merge with one fewer lane. Two 3-lane upstream branches merge into one 5-lane downstream freeway. Two upstream branches have the same geometries: the length between the loading point of vehicles and the merging point is 1,500 feet; the length of downstream freeway is 2,000 feet; the travel demand is 2,400 vehicles/hour.

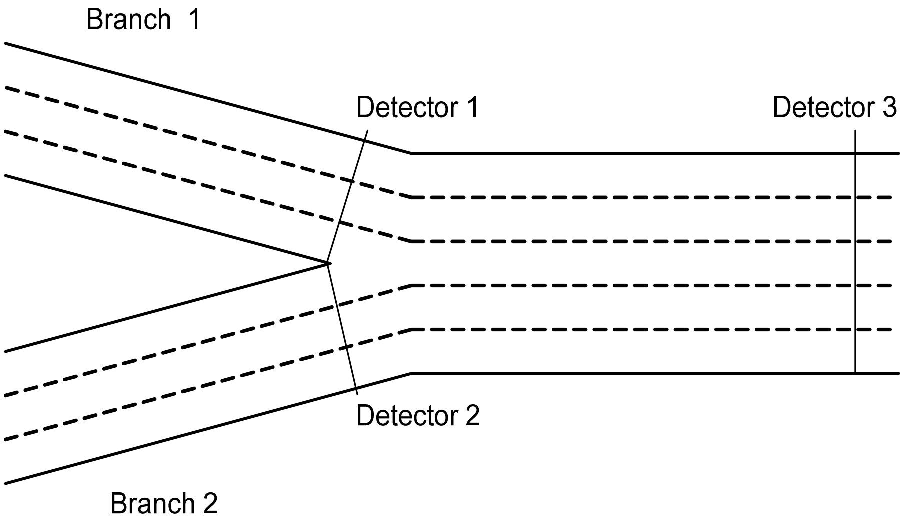

Figure 7: Merge with One Fewer Lane

We created the merge in the simulator and specified the above travel demand. Three detectors are placed at the end of two upstream branches and the end of the downstream freeway separately so that the flow rate can be recorded, as shown in Figure 7. Flow distribution results are demonstrated in Figure 8. Comparison of theoretical demand ratio and actual flow ratio of two upstream branches is shown in Figure 9. Obviously the simulation results are very close to the theoretical results.

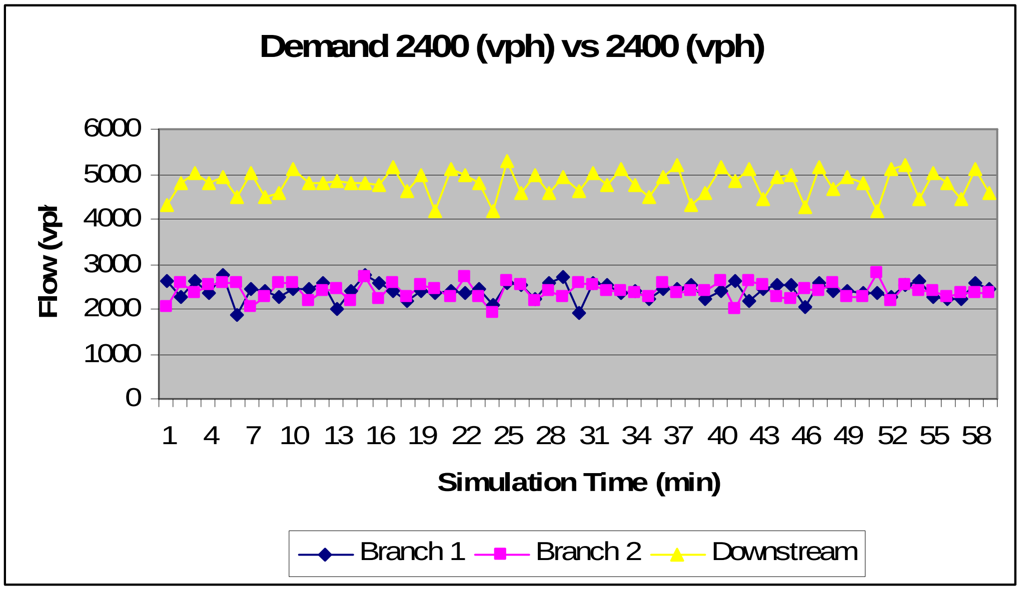

Figure 8: Flow Distribution Demonstration (2400 vs 2400)

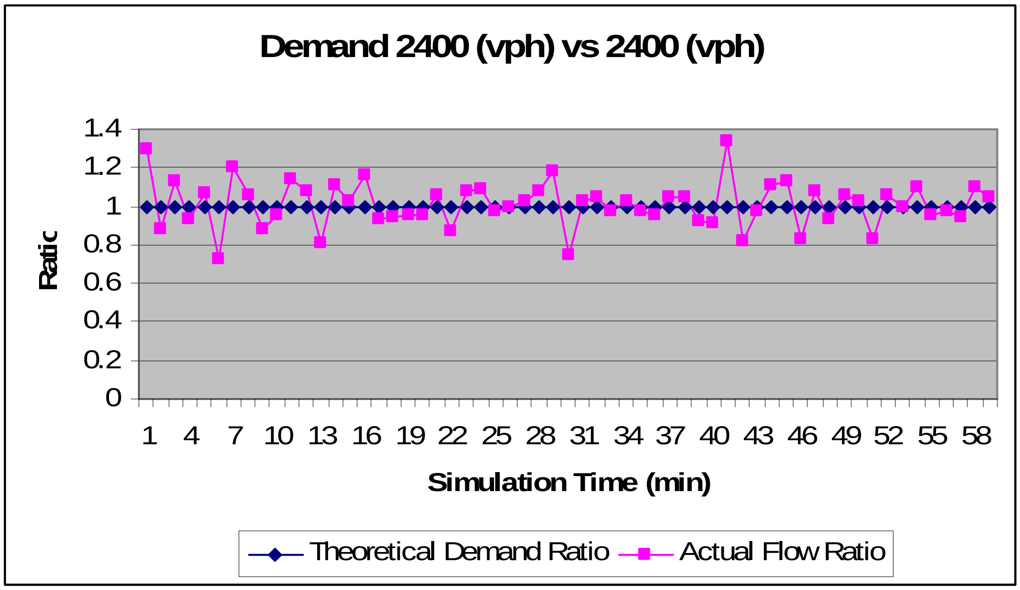

Figure 9: Comparison of Theoretical Demand Ratio and Actual Flow Ratio

5.3. Traffic Signal Control Strategies for Arterials

In networks, or on arterials, signals can be operated on a pretimed basis, or may be partially or fully actuated by arriving vehicles sensed by detectors, or may be coordinated. In pretimed operation, each cycle of the signal follows the same predetermined plan. In semi-actuated operation, detectors are placed on the minor approaches to the intersection; there are no detectors on the major street. The light is green for the major street at all times except when a "call" or actuation is noted on one of the minor approaches. In full actuated operation, every lane of every approach must be monitored by a detector. Green time is allocated in accordance with information from detectors and programmed "rules" established in the controller for capturing and retaining the green. In situations where signals are close enough together so that vehicles arrive at the downstream intersection in platoons, it is necessary to coordinate their green times so that vehicles may move efficiently through the set of signals. It serves no purpose to have drivers held at one signal watching wasted green at a downstream signal, only to arrive there just as the signal turns red(Roess, Prassas et al. 2004).

We created the one-way arterial shown in Figure 10. All the link lengths between two adjacent intersections are 1,800 feet. A platoon of 1, 200 vehicles will go through these five intersections from west to east. At the same time, at the intersection 1, 3 and 5, a platoon of 300 vehicles will go through the corresponding intersection from north to south; at intersection 2 and 4, a platoon of 500 vehicles will go through the corresponding intersection from south to north. The desired platoon speed is 60 ft/s. The cycle length is 60 s, and the effective green time at each intersection is 50% of the cycle length, or 30 s.

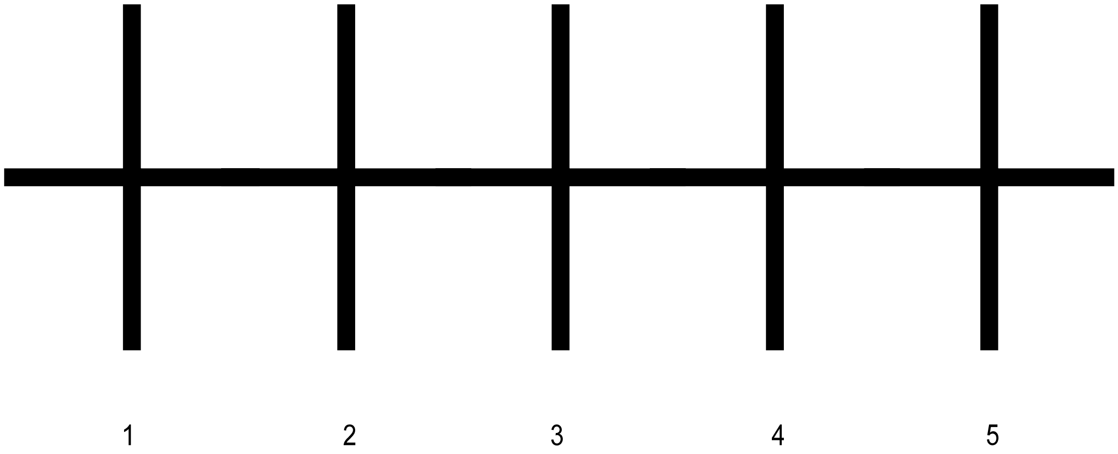

Figure 10: Traffic Signal Control

The simulation results using our simulator are summarized in

Table 4 below. The following observations can be made:

Using actuated control strategy reduced the average intersection delay by more than 7% compared to pretimed control strategy; Using coordinated control strategy reduced the average intersection delay by more than 19% compared to pretimed control strategy.

These observations are consistent with the traffic signal control practice in many cities. This validates the effectiveness of our microscopic traffic simulator.

Table 4: Average Delay Time and Differences with Comparison to Pretimed Control

Intersection	Average Delay Time (s/vehicle)			Differences with Comparison to Pretimed Control	
	Pretimed Control	Actuated Control	Coordinated Control	Actuated Control	Coordinated Control
1	6.3	5.6	5.1	-11.1%	-19.0%
2	6.7	5.3	4.8	-20.9%	-28.4%
3	7.8	7.2	5.7	-7.7%	-26.9%
4	8.4	6.5	5.4	-22.6%	-35.7%
5	7.4	6.4	5.9	-13.5%	-20.3%

6. CONCLUSION

This paper presented a microscopic traffic simulator for evaluation of Intelligent Transportation Systems (ITS) and traffic control and management strategies. This simulator is composed of three modules: traffic flow module, traffic control and management module, and traffic surveillance module. It is implemented in Visual C++ using object-oriented method and visualization technology. Its functionality is demonstrated in three case studies. The preliminary results of these case studies has shown its value in evaluating traffic control and management strategies and potential for evaluation of ITS.

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