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Simulation Laboratory for Evaluating Dynamic Traffic Management Systems

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Advanced traffic management systems (ATMS) and advanced traveler information systems (ATIS) are promising technologies for achieving efficiency in the operation of transportation systems. A simulation-based laboratory environment, MITSIMLab, is presented that is designed for testing and evaluation of dynamic traffic management systems. The core of MITSIMLab is a microscopic traffic simulator (MITSIM) and a traffic management simulator (TMS). MITSIM represents traffic flows in the network, and the TMS represents the traffic management system under evaluation. An important feature of MITSIMLab is its ability to model ATMS or ATIS that generate traffic controls and route guidance based on predicted traffic conditions. A graphical user interface allows visualization of the simulation, including animation of vehicle movements. An ATIS case study with a realistic network is also presented to demonstrate the functionality of MITSIMLab.

In recent years increasing attention has been paid to the development of dynamic route guidance systems, for example, by Mahmassani et al. (*1*) and by Ben-Akiva et al. (*2*), and integrated and adaptive traffic control strategies, for example, by Diakaki and Papageorgiou (*3*) and by Gartner and Stamatiadis (*4*). Although advanced technologies made it possible to develop more sophisticated traffic management strategies, experience has shown that such strategies do not always result in improved performance (*5*). Evaluation is therefore an important element for assessing the performance of alternative designs and answering "what if" questions. Simulation-based evaluation allows for studying the complex interactions among the components of a dynamically managed system under a controlled environment.

A wide variety of simulation models exists [see reports by Koutsopoulos and Yang (*6*) and by Smartest (*7*) for reviews]. Most of these models were developed for evaluation and few for traffic prediction and real-time support of ATIS-ATMS operations [for example, AIMSUN2 (*8*), CORSIM (*9*), HUTSIM (*10*), METROPOLIS (*11*), DYNASMART (*1*), DynaMIT (*12*), INTEGRATION (*13*, *14*), and THOREAU (*15*)].

Despite the large number of individual simulation models, an integrated simulation environment that provides all the functionality needed for evaluation of dynamic traffic management systems is lacking (*16*, pp. 151–156; *17*). A traffic simulation laboratory (MITSIMLab) is presented here that addresses this particular need. MITSIMLab is a computer-based modeling environment that integrates a microscopic traffic simulator and a traffic management simulator (TMS) and supports the generation of prediction-based traffic control and guidance.

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FRAMEWORK

The traffic simulation laboratory consists of a microscopic traffic simulator (MITSIM) and a TMS. MITSIM models traffic flows in the network at the vehicle level, including driver behavior, and the TMS mimics the logic behind the traffic control and traveler information systems under evaluation. The traffic control and route guidance generated in the TMS, according to the strategies to be evaluated, feeds into MITSIM and affects the behavior of individual drivers and hence traffic flow characteristics. The changes in traffic flows are in turn measured by the surveillance system, which provides the TMS the traffic information utilized to generate control and routing strategies.

The interaction between the traffic flows in the network and the control and route guidance is a critical element for modeling dynamic traffic management systems. MITSIMLab provides a laboratory environment for the coupling of traffic management with traffic flows and is designed to

- Represent a wide range of traffic management systems,
- Model drivers' response to real-time traffic information and controls, and
- Calculate measures of effectiveness (MOEs) necessary for the evaluation of traffic management systems and road network designs.

MITSIM uses a microscopic simulation approach, in which movements of individual vehicles and operations of traffic control and surveillance devices are represented in detail. This representation is necessary for evaluating dynamic traffic management systems at the operational level since it allows for capturing the stochastic nature of traffic flow, drivers' response to real-time traffic information, and operations of surveillance sensors.

The TMS has a generic structure that allows testing of a wide range of control and guidance strategies (for example, reactive, proactive). It supports a rolling-horizon implementation of control and route guidance and is capable of simulating ATMS-ATIS systems with advanced capabilities including traffic prediction. The traffic prediction module utilizes a mesoscopic traffic simulator. This default traffic prediction module can be replaced by a user-specified traffic predictor (*18*).

MITSIMLab has an integrated graphical user interface (GUI) for visualizing the simulation process. The GUI features animation of the vehicle movements, graphical display of traffic data, and state-of-control devices. It is an essential tool for verification of input data and presentation of simulation output.

MITSIMLab is implemented in C++, using the object-oriented programming model, and can operate in a distributed environment.

MICROSCOPIC TRAFFIC SIMULATOR

MITSIM is based on and extends the model developed by Yang and Koutsopoulos (*19*). It uses a time-based simulation logic in moving vehicles from their origins to destinations. Vehicles calculate their acceleration rates and make decisions on path choices and lane changes according to routing, car-following, lane-changing, event, and signal response logic. Speeds and positions of vehicles and states of the surveillance sensors are updated at user-specified intervals.

The main elements of MITSIM are the road network, travel demand, vehicle routing, vehicle movement, and output modules.

Road Network

Network Representation

The network can be created using a graphical editor named Road Network Editor. 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.

Traffic Surveillance

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

Traffic Controls

MITSIM 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.

Incidents

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 TMS.

Travel Demand

MITSIM accepts as input time-dependent origin-to-destination (OD) tables. 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 a global fleet mix, specified in a parameter file. Vehicle type is a combination of vehicle class (e.g., high- or low-performance passenger cars, buses, trucks, trailer-trucks), 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 vehicle 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 described in a later section.

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 queue and waits to enter the network during subsequent time intervals.

Vehicle Routing

MITSIM 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 TMS. For sophisticated ATIS-ATMS systems, for example, predicted travel times can be used. 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. The frequency at which VMS messages are updated depends on the specification of the ATIS. Any vehicle may respond to VMS according to a prespecified compliance rate. Modified logit-based route choice models (*20*, *21*) are used to capture drivers' route choice decisions and response to traffic information.

Vehicle Movements

MITSIM moves individual vehicles according to acceleration, lane-changing, and merging logic embedded in the simulator.

Acceleration

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, 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 car-following model draws on previous research (*22*; *23,* pp. 1–13; *24,* pp. 95–107) and is detailed by Yang (*21*) and Ahmed (*25*).

Lane Changing

The lane-changing model is based on work by Gipps (*26*) and 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 LUS or VMS. 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.

For more information on the lane-change models, see work by Ahmed (*25*) and by Ahmed et al. (*27*).

Merging

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.

Courtesy Yielding and Forced Merging

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.

Simulation Output

The output from MITSIM can be classified into three categories: sensor readings, MOEs, and animation graphics. Because of the stochastic nature of the simulation, multiple simulation runs should be conducted for each scenario to obtain statistically significant evaluation results.

Sensor Readings

Point sensor data, such as traffic counts, occupancies, and speeds, are reported to the TMS 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.

Measures of Effectiveness

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.

Graphical User Interface

MITSIM includes a 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.

TRAFFIC MANAGEMENT SIMULATOR

The TMS mimics the traffic control and information systems under evaluation. Besides modeling the traditional pretimed and traffic adaptive control systems, the TMS is designed to support the simulation of dynamic traffic management systems with predictive capabilities. Figure 1 illustrates the main components of the TMS and their interactions with MITSIM. This generic structure can represent different TMS designs with varying levels of sophistication.

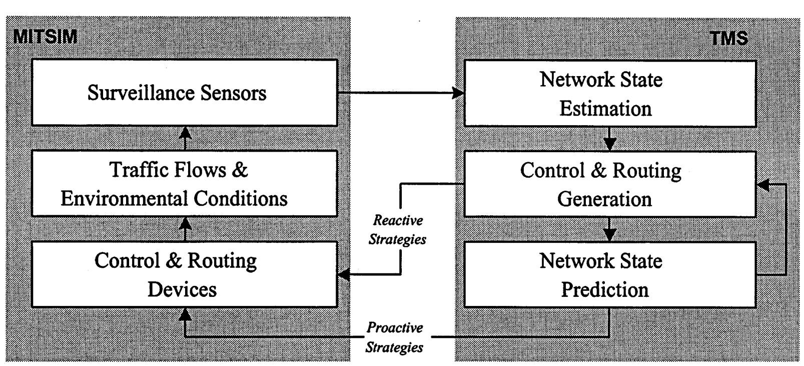

FIGURE 1 Generic structure of dynamic traffic management systems.

The role of network state estimation is to obtain the best estimate of the current network state utilizing the data obtained from the surveillance system. The generation of control strategies and routing information can be reactive or proactive. The reactive approach consists of predetermined control laws that depend only on the current network state. In the proactive case, a system is able to predict future traffic conditions and optimize traffic control and routing strategies on the basis of predicted traffic conditions. In this case the generation of control and routing strategies takes place through an iterative process. Given a proposed strategy, traffic conditions on the network are predicted and the performance of the candidate strategy is evaluated. One of two actions is taken on the basis of the evaluation: (*a*) if a satisfactory strategy has been identified, the strategy is implemented, or (*b*) if additional strategies need to be tested, another generation-prediction iteration is conducted.

Route Guidance

Reactive Route Guidance System

A system with reactive route guidance is simulated in the TMS as follows:

- The average travel time for each link in the network is updated periodically on the basis of speeds measured by the surveillance sensors or speeds and travel times experienced by probe vehicles.
- The travel time from each link to the destination of a path is recalculated on the basis of the updated link travel times.
- Drivers who have access to the updated information choose routes and make en-route decisions based on the updated path travel times using a probabilistic route choice model.

Proactive Route Guidance System

Predictive route information systems have the potential to minimize the inconsistency between provided information and drivers' experience and avoid the overreaction problem discussed by many researchers [for example, by Kaysi et al. (*28*)]. In the literature there are several approaches for generation of proactive route guidance (*1*, *12*, *29*). A simulation-based approach is adopted here because of its flexibility (e.g., representation of travel behavior).

In calculating the travel times that are used for guidance generation, projected (rather than historical or currently measured) time-variant link travel times are used; that is,

$$C_i(t) = c_{i1}(t) + c_{i2}[t + c_{i1}(t)] + \cdots$$

where $C_i(t)$ is the travel time on path i given departure time t, and $c_{ij}(t)$ is the travel time on link j of path i for a driver entering the link at time t. These travel times depend not only on traffic conditions at time t but also on the past and future route choices made by drivers.

In modeling proactive route guidance systems, the TMS updates route information and guidance by assuming a rolling-horizon implementation. Traffic prediction and guidance are periodically updated for a given time horizon.

The implementation of the TMS allows the user to study the sensitivity of the performance of the system to several ATIS design parameters (see Figure 2):

- Rolling-horizon length (T) specifies the time period for which prediction takes place. This length is a function of the maximum trip length.
- Rolling-horizon step size (s) specifies how often prediction is conducted. It is determined on the basis of level of variation in traffic conditions over time, occurrence of incidents, and available computational resources.
- Information resolution (Δt) defines the length of time intervals within which link travel times are treated as constants.
- Computational delay (θ) represents the computational time for control and routing generation.

The main other elements of a proactive route guidance system include network state estimation, network state prediction, and guidance generation modules (see Figure 1).

Network State Estimation

The current network state (e.g., link flows, densities) is the starting point for traffic prediction and guidance generation. The network state estimation module estimates the current network state based on historical and real-time traffic data obtained from the surveillance system. Research is currently under way to develop such a module (*12*). In this paper it is assumed that the true network state—the state observed in MITSIM—is available to the TMS with some user-specified error. Hence, for evaluation purposes, the system's sensitivity to the accuracy of network state estimation can be tested.

Network State Prediction

The network state prediction module forecasts future traffic conditions based on the current network state, the proposed control and routing strategies, and predicted OD flows. Time-dependent OD flows are a key input to many ATIS-ATMS systems. For the purpose

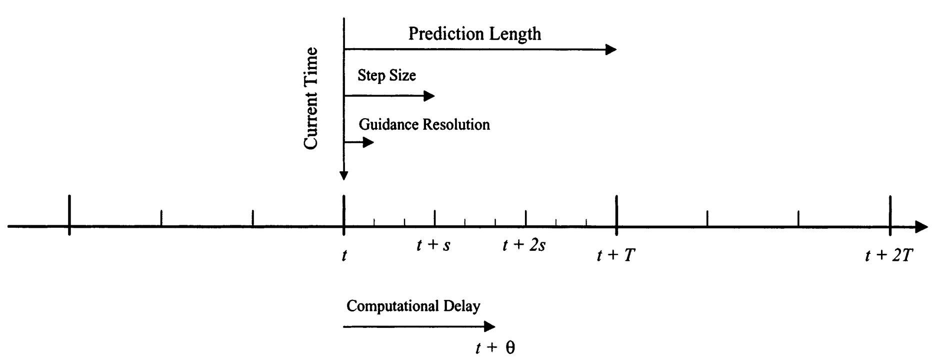

FIGURE 2 Rolling-horizon implementation of traffic prediction.

of evaluating the robustness of a particular control and route guidance system's design with respect to the error in the prediction of OD flows, a dummy module is employed to provide the time-dependent OD matrices at a user-defined level of accuracy. This module takes the input OD matrices specified in a scenario and randomly permutes the "true OD matrices" with noise that represents prediction errors.

A mesoscopic traffic simulator (MesoTS) is used for predicting traffic conditions for a given initial network state and OD flow prediction. Vehicles in the MesoTS are randomly assigned type and access to ATIS according to predefined distributions. Drivers choose routes and make route-switching decisions in response to information according to logit-based models. Vehicles in the MesoTS are organized in traffic cells consisting of vehicles that move together according to the same traffic dynamics. A traffic cell only stores the speeds of the head and tail vehicles. In a link connected to multiple downstream links, cells mutate into traffic streams consisting of vehicles moving to the same downstream link. Speeds of individual vehicles are interpolated on the basis of their positions and the speeds of the head and tail vehicles of the traffic cell or stream to which they belong. Traffic cells merge and split according to predefined thresholds, $d_{\min}$ and $d_{\max}$. Two cells merge into a longer cell (Cells i and j in Figure 3*a*) when the distance between them becomes less than $d_{\min}$. A cell is split into two cells (Cell j in Figure 3*b*) when the distance between two consecutive vehicles becomes greater than $d_{\max}$.

The MesoTS uses two models to capture traffic dynamics: a speed-density model and a cell-following model. The speed-density model calculates the speed for the last vehicle in the traffic cell according to the speed-density function associated with the corresponding segment. The cell-following model calculates the speed of the head vehicle in a traffic cell. If there is no cell in front or the distance from the front cell is greater than a predefined threshold, the free-flow speed of the segment is used; otherwise, the speed is a function of the free-flow speed and the tail speed of the leading traffic cell. The speeds of the vehicles between the head and tail vehicles are interpolated. A traffic cell may shrink or expand depending on whether its tail speed is higher or lower than its head speed.

The simulation time is divided into periods of constant capacity. At the beginning of each period, the simulator computes capacities for each segment and turning movement at intersections. Recommendations from the *Highway Capacity Manual* (*30*) can be used for this purpose. A vehicle is allowed to move to the next segment or a new link only if there is available capacity.

The output of the MesoTS includes the flows and travel times on individual links and paths. These travel times are then used by the TMS for guidance generation.

Guidance Generation

The route guidance provided by the ATIS may take various forms, ranging from descriptive (i.e., traffic information such as travel times, delays, and queues) to prescriptive (route recommendations on VMS or in-vehicle units, etc.). The main objective of the guidance generation module is the generation of consistent guidance, that is, guidance with the smallest difference between the information that drivers receive and the conditions they will most likely experience.

The TMS generates guidance based on predicted travel times, which are obtained iteratively using the MesoTS. Figure 4 depicts this process. At the start of the simulation, estimates of travel times are provided to informed drivers, who in turn make their route choices. Their choices influence the link flows and travel times. These "experienced" flows and travel times are used to modify the route information to be provided in the next iteration. This process continues until the "predicted" and the "experienced" travel times converge or a predetermined number of iterations is reached. In the latter case, the iteration with the smallest difference is chosen.

A heuristic algorithm (*2*) based on the method of successive averages (MSA) is used in updating the travel times at iteration $k+1$:

$$g_{ij}^{k+1} = (1 - \lambda^k)g_{ij}^k + \lambda^k \times e_{ij}^k$$

where

i = paths (or links),
j = time interval,
g_{ij}^k = travel times used for guidance,
e_{ij}^k = experienced travel times, and
λ^k = update step size.

Step size λ^k can be set to appropriate values such as $1/(k+1)$.

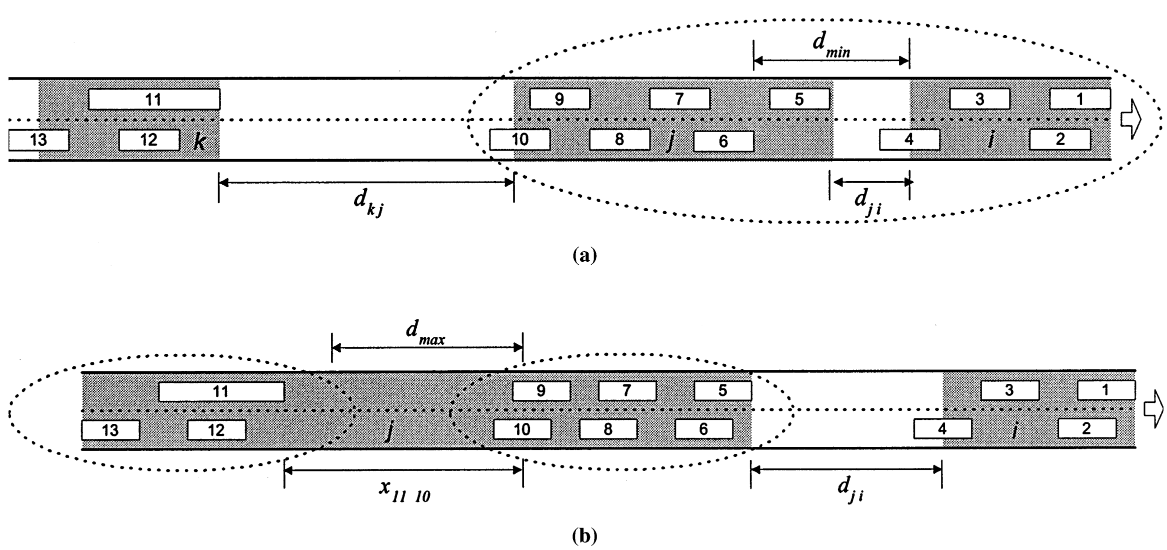

FIGURE 3 Traffic cells: (*a*) merge and (*b*) split.

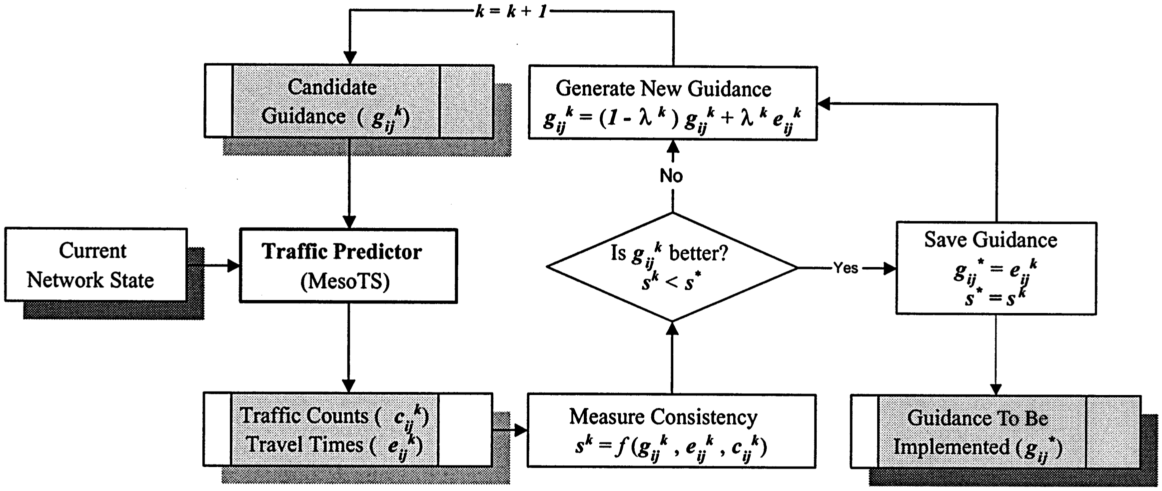

FIGURE 4 Generation of predictive route guidance.

The criterion used to measure the consistency between predicted and experienced travel times could be defined, for example, as

$$s^k = \sum_i \sum_j f_{ij}^k \left| g_{ij}^k - e_{ij}^k \right|$$

where s^k is the consistency measurement of the guidance g_{ij}^k and f_{ij}^k is the number of drivers who experience the travel times e_{ij}^k.

This algorithm does not guarantee that a consistent solution, which may not even exist, can be found. In such cases, the travel time information g_{ij}^k yielding the minimum s^k, among all iterations, is implemented. Further research is needed to understand the properties of this approach and, if necessary, develop new algorithms that generate consistent guidance (*31*).

Traffic Control

The TMS simulates the operations of a wide range of traffic control and advisory 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.

Pretimed Controllers

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

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 TMS and activated through a data file or coded as a new customized controller module to interface with the TMS. 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.

Metering Controllers

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 (*32*) or be set dynamically by external control modules (*33*). 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 (*34*).

Incident Detection and Management

Several freeway incident detection algorithms and a rule-based incident management scheme that influences the state of lane control devices are implemented in the TMS. The incident detection algorithms already implemented include the McMaster and APID algorithms (*35–36*; *37*, pp. 295–310) and algorithms proposed by Thirukkonda (*38*). 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).

CASE STUDY

Use of MITSIMLab is demonstrated in a case study to evaluate two approaches in providing real-time traffic information, one based on current prevailing traffic conditions and the other based on predicted traffic conditions. The network used in this case study is based on the A10 Beltway in Amsterdam, The Netherlands. Figure 5 shows the testing network and the OD pairs chosen for the calculation of the evaluation statistics. The network consists of two loops intersecting with five major freeways and 20 interchanges of various sizes (75 ramp intersections). It contains 195 nodes, 309 links, and 365 OD pairs. The total length of the test network is about 130 link-km (341 lane-km).

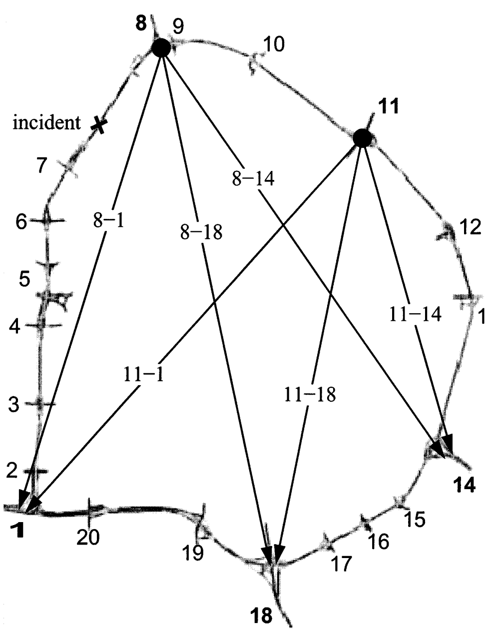

FIGURE 5 Amsterdam beltway and representative OD pairs chosen for evaluation.

Testing the two guidance generation strategies in MITSIMLab requires the following steps:

- Generation of time-dependent OD flows,
- Generation of paths and habitual travel times,
- Calibration of the MesoTS,
- Definition of appropriate scenarios, and
- Comparison of the performance of the two strategies using appropriate MOEs.

The sequential model described by Cascetta et al. (*39*) was used to estimate time-dependent OD flows (from on-ramps to off-ramps) using observed link traffic counts and speed data. Application of this model yielded OD matrices that resulted in a 2 percent error in link counts (15-min intervals). The dynamic OD estimation model and the data used in the analysis are detailed by Ashok (*40*).

For every OD pair in the network, a set of reasonable paths connecting that OD pair was generated (a total of about 1,500 paths). Time-variant habitual travel times on these paths were calculated by simulating drivers' day-to-day travel decisions using MITSIM. This process begins with an initial estimate of link travel times (i.e., observed or free-flow travel times). Drivers make path choices on the basis of those initial estimates, and traffic flows are simulated. The travel times drivers use to make route choices on the following day are the weighted average of the travel times used in choosing their routes and the experienced travel times for the current day. MITSIM is run repeatedly until the difference between expected and experienced link travel times is adequately small. The final link travel times are then used to compute time-variant historical travel times and habitual paths in the network.

Since, in the context of the laboratory, MITSIM represents the real world, data from MITSIM were used to calibrate the speed-density functions used in the MesoTS. Comparison of the MesoTS and MITSIM output under several test scenarios indicates a reasonable fit (*21*).

In order to evaluate the effectiveness of the two guidance generation strategies, traffic flows during a 2.25-h-long morning peak period, corresponding to about 70,000 vehicle trips, were simulated for the following scenarios:

- No real-time information: All drivers use their habitual routes based on time-variant historical travel times. In this base scenario no real-time traffic information is provided.
- Naive information: Every 5 min informed drivers evaluate their paths using the latest link travel times.
- Predictive information: Every 15 min the system predicts traffic conditions for the next 45 min (discretized into 5-min time intervals). Informed drivers revise their routes on the basis of predicted travel times.

In all scenarios an incident that lasted 20 min and blocked two lanes (see Figure 5) was simulated. It is assumed, under all scenarios, that 30 percent of drivers had access to ATIS. The approach described earlier, in the section on route guidance, was used for guidance generation, with a maximum of five iterations. The computational delay was assumed to be 1 min.

A comparison of average travel times shows that the delay is reduced when drivers are provided with real-time traffic information. Under normal traffic conditions, the average travel time in the network is about 6 min. The 20-min incident caused a 28 percent increase in the average travel time in the base case. With real-time traffic information, travel time savings of about 2 to 3 percent are experienced in

TABLE 1 Changes in Average Travel Time for Representative OD Pairs

Group	OD Pairs	w/o Guidance (minutes)	w/ Guidance	
			Naïve (% change)	Predictive (% change)
Informed Drivers	8-14	14.7	-7.8	-2.3
	8-18	18.9	-7.1	-9.4
	8-1	20.9	-16.6	-15.5
	11-14	5.8	38.3	29.6
	11-18	9.0	33.1	22.4
	11-1	17.8	-19.0	-17.6
Uninformed Drivers	8-14	14.7	-9.3	-4.2
	8-18	18.9	-5.5	-3.7
	8-1	20.9	-14.0	-17.4
	11-14	5.8	41.1	28.9
	11-18	9.0	30.6	21.0
	11-1	17.8	-11.8	-9.7

both information scenarios. Although the informed drivers benefit more (3 to 4 percent on average) from real-time information, uninformed drivers also benefit (2 to 3 percent on average) because of improved utilization of network capacity. This delay reduction is achieved by some informed drivers traveling slightly longer distances (a 1 to 2 percent increase in distance traveled) using alternate routes.

Table 1 summarizes the changes in average travel times for selected OD pairs. The travel time savings with guidance vary across OD pairs, and for certain OD pairs the travel times were actually increased. This is expected since traffic in the A10 network is congested and several sections operate at capacity. In general, travel times under naive and predictive guidance did not differ significantly for the OD pairs that experienced improvement (e.g., 8-14, 8-18, and 8-1). However, for pairs that generally experienced an increase in travel time (e.g., 11-14 and 11-18), the percent increase is lower under the predictive scenario. These results emphasize the importance of prediction-based guidance for avoiding the adverse effects of overreaction.

The computational performance of the traffic simulation laboratory was satisfactory. MITSIM alone took about 120 min to complete a 135-min simulation on an SGI Indy R4400 workstation (200 MHz). The MesoTS took about 6 min to complete a 135-min simulation. The running time for the predictive guidance scenario, in which all modules of MITSIMLab were used, was about 300 min using two processors (one for MITSIM and the other for the TMS and MesoTS). This increase in computation time is due to the communication and synchronization overhead.

CONCLUSIONS

A traffic simulation laboratory for evaluation of dynamic traffic management systems has been presented. The system integrates a microscopic traffic simulator, a traffic management simulator, and traffic prediction capabilities (based on mesoscopic traffic simulation) in a laboratory environment. It provides the basic infrastructure for modeling ATMS and ATIS operations. The functionality of MITSIMLab is demonstrated in an ATIS case study utilizing Amsterdam's A10 Beltway. The results of the case study support the value of information in reducing traffic congestion and the importance of prediction in providing traffic information. The computational performance of MITSIMLab is also promising and indicates that MITSIMLab can be a valuable tool for evaluating large-scale dynamic traffic management systems.

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