

# **A Simulation Laboratory for Evaluating Dynamic Traffic Management Systems**

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## **Abstract**

Advanced Traffic Management Systems (ATMS) and Advanced Traveler Information Systems (ATIS) are promising technologies for achieving efficiency in the operation of transportation systems. This paper presents a simulation based laboratory environment, MITSIMLab, 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, while TMS represents the traffic management system under evaluation. An important feature of MITSIMLab is its ability to model ATMS/ATIS which 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.

**Keywords:** Traffic Simulation, Traffic Prediction, ATIS, ATMS

# 1 Introduction

In recent years increasing attention has been paid to the development of dynamic route guidance systems [e.g. Mahmassani et al., 1994, Ben-Akiva et al., 1997] and integrated and adaptive traffic control strategies [e.g. Diakaki and Papageorgiou, 1995, Gartner and Stamatidis, 1997]. While 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 [Gartner et al., 1995]. 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 exist [see Koutsopoulos and Yang, 1992, Smartest, 1997, 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, AIMSUM2 [Barcelo and Ferrer, 1995], CORSIM [FHWA, 1996], HUTSIM [Kosonen, 1996], METROPOLIS [de Palma et al., 1996], DYNASMART [Mahmassani et al., 1994], DynaMIT [Ben-Akiva et al., 1996], INTEGRATION [van Aerde and Yagar, 1988, van Aerde, 1992], THOREAU [Codelli et al., 1992]).

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 [Lin, 1993, Underwood and Gehring, 1994]. This paper presents a traffic simulation laboratory (MITSIMLab) that addresses this particular need. MITSIMLab is a computer-based modeling environment that integrates a microscopic traffic simulator and a traffic management simulator and supports prediction-based traffic control and guidance generation.

## 2 Framework

The traffic simulation laboratory consists of a Microscopic Traffic SIMulator (MITSIM) and a Traffic Management Simulator (TMS). MITSIM models traffic flows in the network at the

vehicle level, including driver behavior, while TMS mimics the logic behind the traffic control and traveler information systems under evaluation. The traffic control and route guidance generated in TMS, according to the strategies to be evaluated, feed into MITSIM and affect 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 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:

- (a) represent a wide range of traffic management systems;
- (b) model drivers' response to real-time traffic information and controls; and,
- (c) calculate 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.

TMS has a generic structure that allows testing of a wide range of control and guidance strategies (for example, reactive, proactive, etc.) 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" [Ben-Akiva et al., 1998].

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.

### 3 Microscopic Traffic Simulator

MITSIM is based on and extends the model developed by Yang and Koutsopoulos [1996]. 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 movements and output modules.

#### 3.1 Road Network

**Network Representation:** The network can be created using a graphical editor, named *Road Network Editor*. The network database includes description of all network objects, lane connections, lane-use privileges (ETC, HOV, etc.), 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 areawide 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 which determine where vehicles may start

responding to them.

**Incidents:** An incident may completely block one or more lanes and/or produce a rubber necking effect where vehicles slow down to a particular speed. Incidents are also characterized by their duration (clearance time) which may depend on the detection delay and response plans of TMS.

## 3.2 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 based on 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, and so on), *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 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 pre-trip path, if not uniquely specified in the input file, will be calculated based on route choice models described in section 3.3.

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

## 3.3 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 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 pre-specified compliance rate. Modified logit based route choice models [Cascetta et al., 1996, Yang, 1997] are used to capture drivers’ route choice decisions and response to traffic information.

### 3.4 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.

A vehicle, based on its time headway from its leader, can be in *free-flowing*, *car-following*, and *emergency-decelerating* regime. The acceleration in the free-flowing regime is a function of the vehicle’s desired speed, while in the car-following and emergency-decelerating regimes, the acceleration is calculated based on headway and speeds of the vehicles concerned. The car-following model draws upon previous research [Herman et al., 1959, Herman and Rothery, 1963, Wicks, 1977] and is detailed in Yang [1997] and Ahmed [1999].

**Lane Changing:** The lane changing model is based on Gipps [1986] 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. Discretionary lane change refers to cases in which drivers change lane in order to improve their driving experience. 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, etc.

Once a vehicle has decided to change lanes, it 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 Ahmed et al. [1996], Ahmed [1999].

**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: (i) priority merging; and (ii) non-priority merging. Priority merging includes merging from ramps to freeways, and from minor streets to major streets. Non-priority merging occurs, for example, at the 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 where a driver decelerates to make space for another vehicle switching into its lane. Forced merging refers to the cases where 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, its state is maintained until the merge or lane change is completed or is canceled after a maximum amount of time has elapsed.

### 3.5 Simulation Output

The output from MITSIM can be classified into three categories: sensor readings, MOEs, 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.

**Sensor Readings:** Point sensor data, such as traffic counts, occupancies, and speeds, are reported to TMS at a given frequency and logged into output files. Sensor ID and vehicle information such as vehicle ID, speed, etc., are reported each time a probe vehicle passes a point to point sensor.

**Measures of Effectiveness (MOE):** Detailed data on vehicle trajectory and trip information can be recorded during the simulation. Traffic volumes, average link and path travel times of various level 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, etc. can be developed.

**Graphical User Interface (GUI):** MITSIM includes a GUI for visualization of the simulation input and output.

- (a) 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.
- (b) Sensor measurements (e.g. counts) are displayed and refreshed.
- (c) The state of traffic control devices is displayed by dedicated symbols.
- (d) Vehicle movements are animated and information such as vehicle type, car-following and lane-changing status are selectively displayed.

## 4 Traffic Management Simulator

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

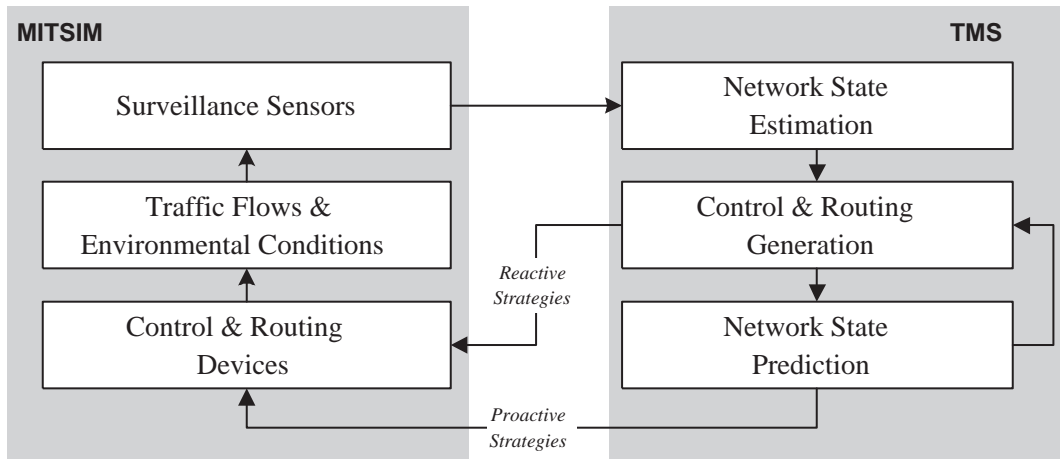


Figure 1: Generic structure of dynamic traffic management systems

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 pre-determined 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 based on 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 are taken based on the evaluation: (i) if a satisfactory strategy has been identified, the strategy is implemented; or, (ii) if additional strategies need to be tested, another generation-prediction iteration is conducted.

## 4.1 Route Guidance

### 4.1.1 Reactive Route Guidance System

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

- (a) The average travel time for each link in the network is updated periodically based on speeds measured by the surveillance sensors or the speeds and travel times that probe vehicles experienced.
- (b) The travel time from each link to the destination of a path is recalculated based on the updated link travel times.
- (c) 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.

### 4.1.2 Proactive Route Guidance System

Predictive route information systems have the potential to minimize the inconsistency between provided information and drivers' experience and avoid the *over-reaction* problem discussed by many researchers (see for example, Kaysi et al. [1993]). In the literature there are several approaches for generation of proactive route guidance [e.g. Mahmassani et al., 1994, Ben-Akiva et al., 1996, Ran and Boyce, 1996]. 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, i.e.:

$$C_i(t) = c_{i1}(t) + c_{i2}(t + c_{i1}(t)) + \dots \quad (1)$$

where:

$C_i(t)$  = travel time on path  $i$  given departure time  $t$ ;

$c_{ij}(t)$  = travel time on link  $j$  of path  $i$  for a driver entering the link at time  $t$ .

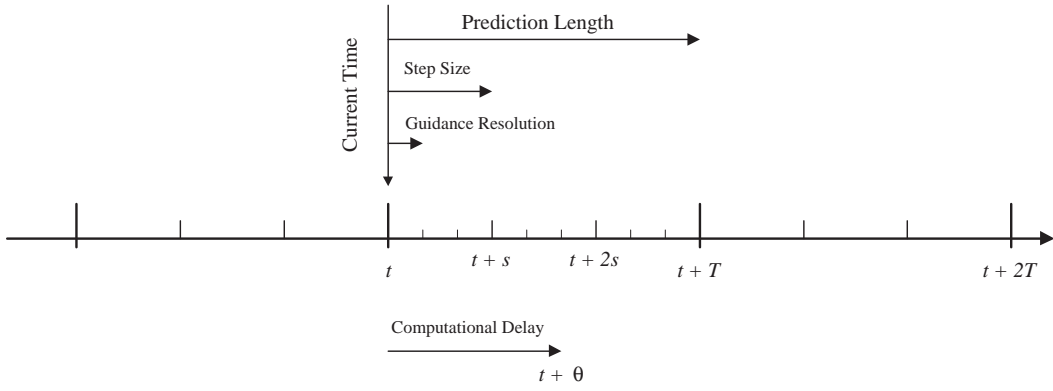


Figure 2: Rolling horizon implementation of traffic prediction

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, TMS updates route information and guidance assuming a rolling horizon implementation. Traffic prediction and guidance are periodically updated for a given time horizon.

The implementation of 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 based on level of variation in traffic conditions over time, occurrence of incidents, and available computational resources.
- *Information resolution* ( $\Delta t$ ): defines the length of time intervals within which link travel times are treated as constants.
- *Computational delay* ( $\theta$ ): represents the computational time for control and routing generation.

The main other elements of a proactive route guidance system include the 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 start point for a 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 underway to develop such a module [Ben-Akiva et al., 1996]. In this paper we assume that the true network state – the state observed in MITSIM – is available to TMS with some user specified error. Hence, for evaluation purposes, the system’s sensitivity to the accuracy of network state estimation can be tested.

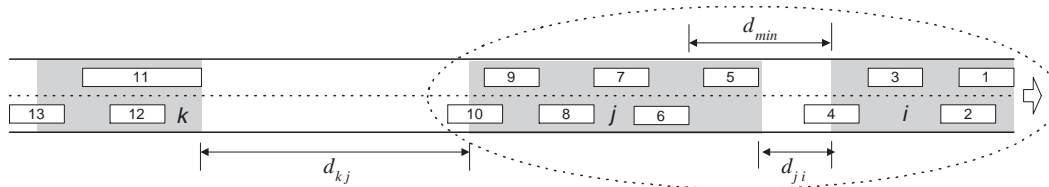
## Network State Prediction

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 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 MesoTS are randomly assigned type and access to ATIS according to predefined distributions. Drivers choose route and make route switching decisions in response to information according to logit based models. Vehicles in 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 based on their positions and the speeds of the head and tail vehicles of the traffic cell or stream they belong to. 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 3a) when the distance between them becomes less than  $d_{min}$ . A cell is split into two cells (cell  $j$  in Figure 3b) when the distance between two consecutive vehicles becomes greater than  $d_{max}$ .

(3a) Merge



(3b) Split

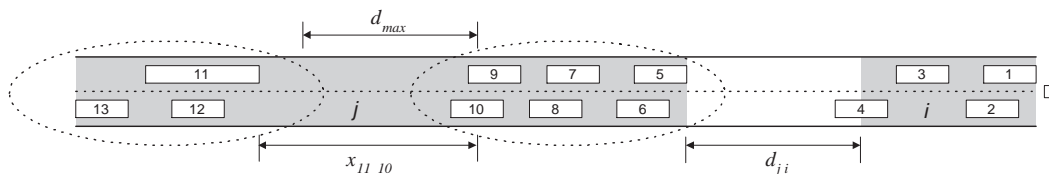


Figure 3: Merge and split of traffic cells

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 HCM [1985] 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 MesoTS includes the flows and travel times on individual links and paths. These travel times are then used by 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, etc.) to prescriptive (e.g. route recommendations on VMS or in-vehicle units, etc.). The main objective of the guidance generation module is the generation of “consistent” guidance, i.e., guidance with the smallest difference between the information that drivers receive and the conditions they will, most likely, experience.

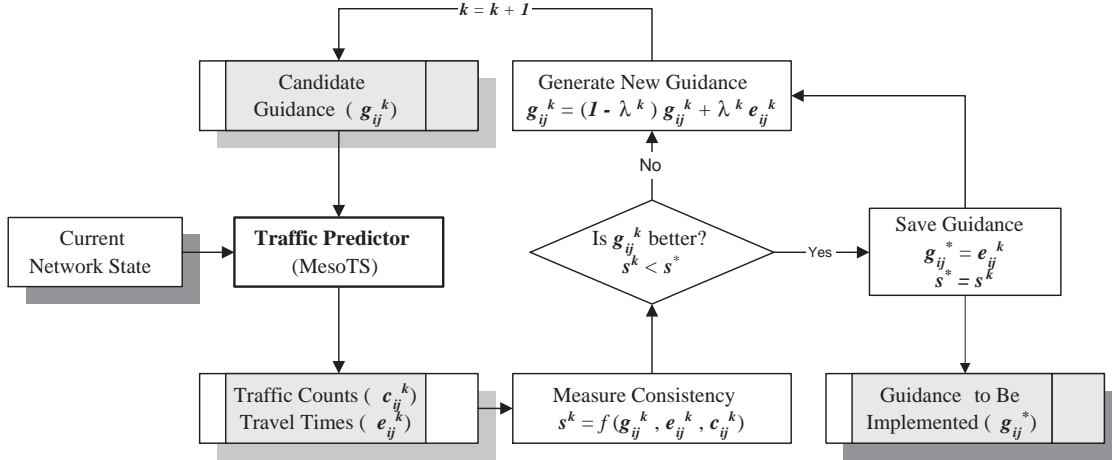


Figure 4: Generation of predictive route guidance

TMS generates guidance based on predicted travel times which are obtained iteratively using MesoTS. Figure 4 depicts this process. At the start of the simulation, estimates of travel-times are provided to the 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 pre-determined number of iterations is reached. In the latter case, the iteration with the smallest difference is chosen.

A heuristic algorithm based on the method of successive averages (MSA) is used in updating the travel times at iteration  $k + 1$  [Ben-Akiva et al., 1997]:

$$g_{ij}^{k+1} = (1 - \lambda^k) g_{ij}^k + \lambda^k e_{ij}^k \quad (2)$$

where  $i$  represents paths (or links) and  $j$  time interval, and:

- $g_{ij}^k$  = travel times used for guidance;
- $e_{ij}^k$  = “experienced” travel times; and,
- $\lambda^k$  = update step size;

The step size  $\lambda^k$  can be set to appropriate values such as  $\frac{1}{k+1}$ .

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

$$s^k = \sum_i \sum_j f_{ij}^k |g_{ij}^k - e_{ij}^k| \quad (3)$$

where:

- $s^k$  = consistency measurement of the guidance  $g_{ij}^k$ ; and,
- $f_{ij}^k$  = 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 [Ben-Akiva et al., 1999].

## 4.2 Traffic Control

TMS simulates the operations of a wide range of traffic control and advisory devices:

- *Intersection controls*: traffic signals, yield and stop signs.
- *Ramp controls*: ramp metering and speed limit signs.

- *Mainline controls*: lane use signs, variable speed limit signs, variable message signs, portal signals at tunnel entrances.

These devices can be controlled by *pre-timed*, *traffic adaptive*, or *metering* controllers. A controller can switch from one type to another based on some predefined logic. Several control strategies that cover the most common control types are already implemented. These pre-programmed strategies can be activated through parameters specified in input files.

#### 4.2.1 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.

#### 4.2.2 Adaptive Controllers

Adaptive controllers use real-time data from surveillance detectors and pre-specified 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 TMS and activated through a data file, or coded as a new customized controller module to interface with 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: (i) signals; (ii) phases; and, (iii) 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 either *extendible*, *callable*, or both. A phase is extendible if its green interval can be extended when detector data satisfies 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 without completing the subsequent phases in the cycle.

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.

### 4.2.3 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 [Papageorgiou et al., 1990] or set dynamically by external control modules [Chen, 1996]. Thus, TMS is capable of simulating systems with a two-level hierarchical control logic where: (i) a system-wide optimization model calculates the desired network state; and, (ii) 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].

### 4.2.4 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 TMS. The incident detection algorithms already implemented include the McMaster and APID algorithms [Persaud and Hall, 1989, Persaud et al., 1990, Masters et al., 1991] and algorithms proposed by Thirukkonda [1999]. These algorithms can also be combined to provide higher detection rate with fewer false alarms.

Incident management is represented by response plans, which determine the state 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 at 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).

## 5 Case Study

We demonstrate the use of MITSIMLab 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-kilometers (341 lane-kilometers).

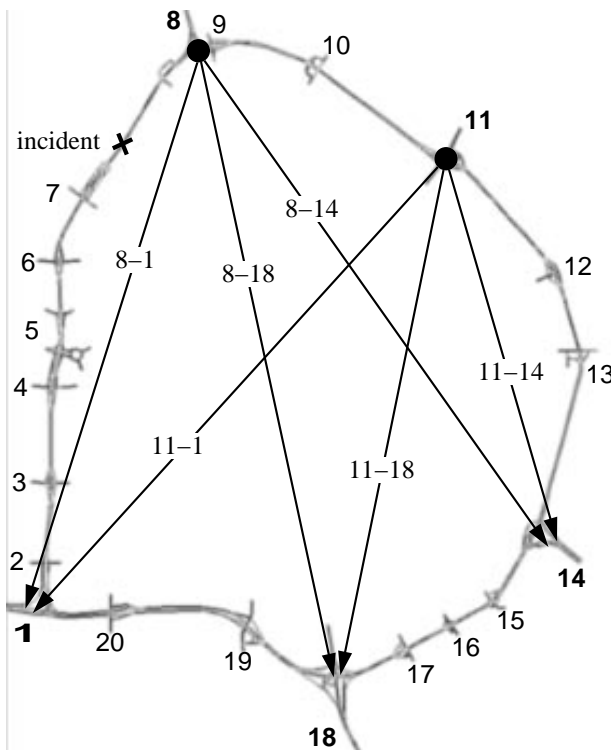


Figure 5: Amsterdam beltway and representative OD pairs chosen for evaluation

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 MesoTS;
- Definition of appropriate scenarios; and
- Comparison of the performance of the two strategies using appropriate MOEs.

The sequential model described in Cascetta et al. [1993] 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% error in link counts (15-minute intervals). The dynamic OD estimation model and the data used in the analysis are detailed in Ashok [1996].

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 based on 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 was used to calibrate the speed-density functions used in MesoTS. Comparison of MesoTS and MITSIM output, under several test scenarios, indicates a reasonable fit [Yang, 1997].

In order to evaluate the effectiveness of the two guidance generation strategies, traffic flows during a 2.25 hour-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 minutes informed drivers evaluate their paths using the latest link travel times.
- *Predictive Information:* Every 15 minutes the system predicts traffic conditions for the next 45 minutes (discretized into 5-minute time intervals). Informed drivers revise their routes based on predicted travel times.

In all scenarios an incident that lasted 20 minutes and blocked two lanes (see Figure 5) was simulated. It is assumed, under all scenarios, that 30% of drivers had access to ATIS. The approach described in section 14 was used for guidance generation, with a maximum of 5 iterations. The computational delay was assumed to be 1 minute.

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 minutes. The 20-minute incident caused an 28% increase in the average travel time in the base case. With real-time traffic information, travel time savings about 2 – 3% are experienced in both information scenarios. While the informed drivers benefit more (3 – 4% on average) from real time information, uninformed drivers also benefit (2 – 3% on average) because of the improved utilization of the network capacity. This delay reduction is achieved by some informed drivers traveling slightly longer distances (an 1 – 2% increase in distance traveled) using alternative 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 significantly differ 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 over-reaction.

Table 1: Changes in Average Travel Time for Representative OD Pairs

Driver Group	OD Pairs	w/o Guidance	w/ Guidance	
			Naive	Predictive
		minutes	change (%)	change (%)
Informed	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
Un-informed	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

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

## 6 Conclusion

We have presented a traffic simulation laboratory for evaluation of dynamic traffic management systems. 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 informa-

tion. 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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