# DynaMIT: a simulation-based system for traffic prediction



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# DynaMIT: a simulation-based system for traffic prediction

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## 1. Introduction

Advanced Traveler Information Systems (ATIS) and Advanced Traffic Management Systems (ATMS) have the potential to contribute to the solution of the traffic congestion problem. However, for these systems to be effective, the generated strategies should be proactive (i.e. based on predicted traffic conditions) as opposed to reactive, in order to avoid many undesirable effects such as overreaction, which reflects the situation where many drivers react to a known current traffic condition in a similar fashion resulting in simply transferring the congestion to another location. DynaMIT (Dynamic Network Assignment for the Management of Information to Travelers) is a real time dynamic traffic assignment system that provides traffic predictions and travel guidance.

DynaMIT generates prediction-based guidance with respect to departure time, pre-trip path and mode choice decisions and en-route path choice decisions. It supports both prescriptive and descriptive information. In order to guarantee the *credibility* of the information system, the guidance provided by DynaMIT is consistent, meaning that it corresponds to traffic conditions that most likely will be experienced by drivers. Hence, DynaMIT provides user-optimal guidance, which implies that users cannot find a path that they would prefer compared to the one they chose based on the provided information.

## 2. Overall Structure

DynaMIT is organized around two main functions: *state estimation*, and *prediction-based guidance generation*. The overall structure with interactions among the various elements of DynaMIT is illustrated in Figure 1.

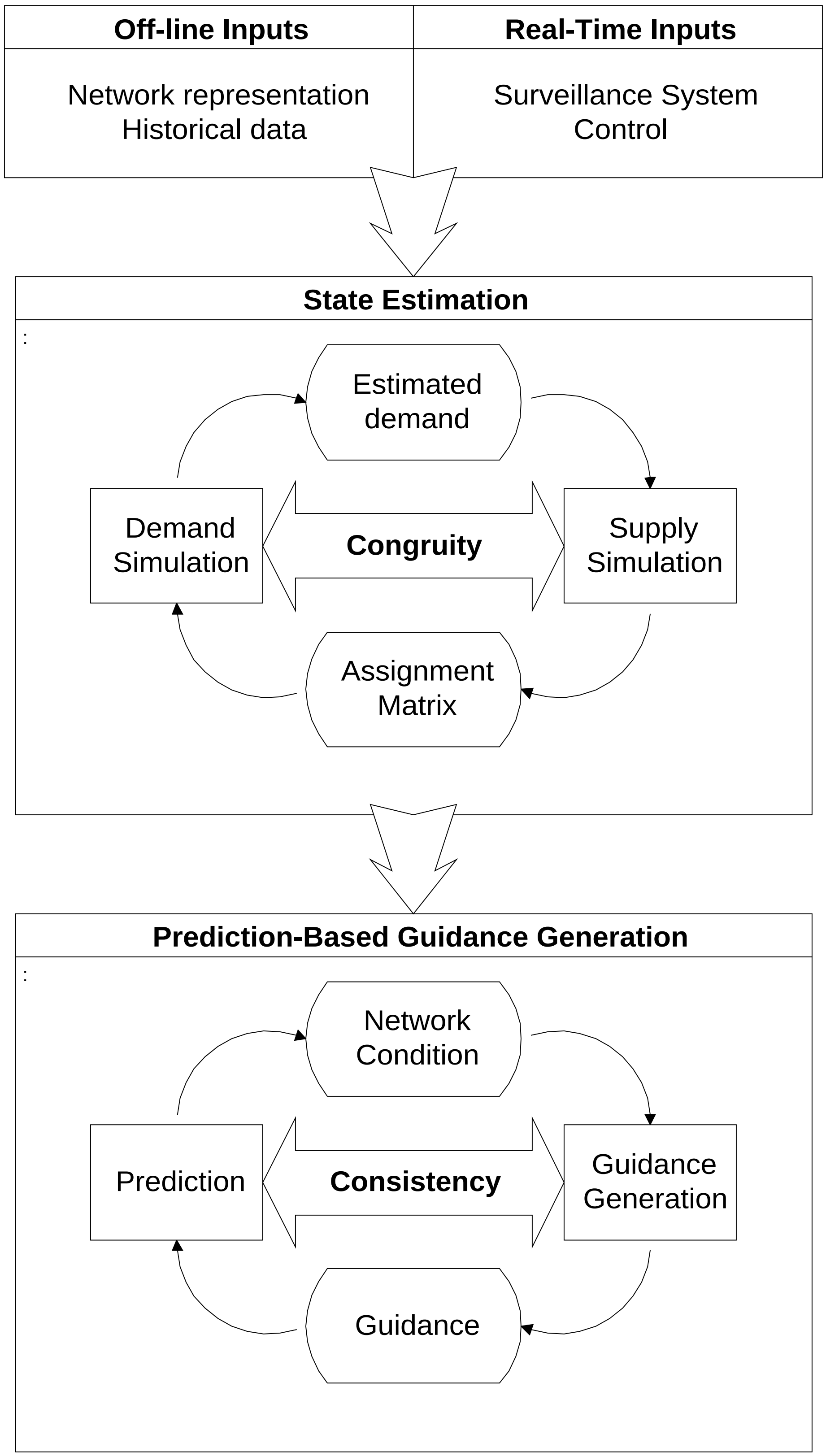


**Figure 1: Structure of DynaMIT**

DynaMIT utilizes both off-line and real-time information. The most important off-line information, in addition to the detailed description of the network, is a database containing historical network conditions. This is the system's memory. The real-time information is provided by the surveillance system and the control system. DynaMIT is designed to operate with a wide range of surveillance and control systems.

The state estimation component determines the current state of the network and the current demand levels given historical and surveillance data. Two simulation tools are being used iteratively in this context: the Supply Simulator and the Demand Simulator (see Antoniou *et al.* and Ben-Akiva *et al.* for more details). The Demand Simulator estimates and predicts Origin-Destination (OD) flows and drivers decisions in term of departure time, mode and route choices. An initial estimate of the demand is directly derived from the data. The Supply Simulator explicitly simulates the interaction between that demand and the network. Assignment Matrices, mapping OD flows into link flows, are produced by the simulator. The Assignment Matrices and real-time observations are then used by the Demand Simulator to obtain a better estimate of the demand. This loop is executed until congruence between demand and supply is obtained, that is when the simulation reproduces sufficiently well the observed data.

The prediction-based guidance generation module provides anticipatory guidance using as input the state estimate. Traffic prediction is performed for a given horizon (e.g. one hour). The Demand Simulator and Supply Simulator are also used for prediction. The guidance generation is based on an iterative process between traffic prediction and candidate guidance strategies. The system enforces consistency between the travel times on which the guidance is based and the travel times which result from travelers' reactions to the guidance.

The quality of the prediction depends on the quality of the current state description, and on the horizon. Therefore, the state of the network is regularly estimated so that all available information is incorporated in a timely fashion, and a new prediction is computed. We illustrate this concept with a simple example (see Figure 2).

It is now 8:00am. DynaMIT starts an execution cycle. It performs a state estimation using data collected during the last 5 minutes. When the state of the network at 8:00 is available, DynaMIT starts predicting for a given horizon, say one hour, and computes a guidance strategy which is consistent with that prediction. At 8:07, DynaMIT has finished the computation, and is ready to implement the guidance strategy on the real network. This strategy will be in effect until a new strategy is generated. Immediately following that, DynaMIT starts a new execution cycle. Now, the state estimation is performed for the last 7 minutes. Indeed, while DynaMIT was busy computing and implementing the new guidance strategy, the surveillance system continued to collect real-time information, and DynaMIT will update its knowledge of the current network conditions using that information. The new network estimate is used as a basis for a new prediction and guidance strategy. And the process continues rolling in a similar fashion during the whole day.

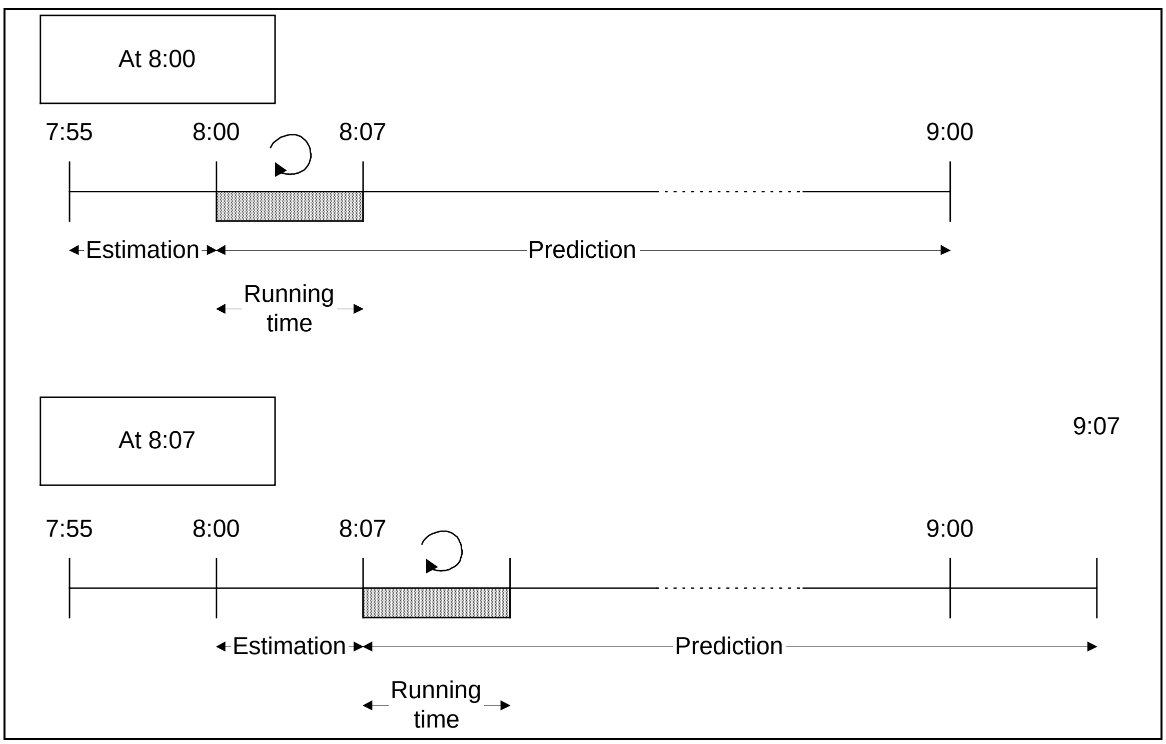


**Figure 2: Rolling horizon**

## 3. Simulation tools

The design of the simulation tools within DynaMIT is based on three main requirements. First, each tool must be used both for estimation of current state and prediction of future network condition. Second, the tools must be able to simulate at different levels of aggregation. Indeed, capturing drivers response to information requires a disaggregate representation, where almost each driver is included with his/her behavior. Also, OD estimation and prediction takes place at an aggregate level, and the models must be consistent with the input data from the surveillance system, available at an aggregate level. For these reasons, the simulation tools within DynaMIT combine microscopic and macroscopic models and, therefore, are called "mesoscopic simulators".

### 3.1 Mesoscopic Demand Simulation

The Mesoscopic Demand Simulator is first described in its "estimation mode". The "prediction mode" is very similar, and is described at the end of this section.

In order to estimate the current demand, the Demand Simulator separates the analysis into three components, as illustrated in Figure 3. First, as part of the historical data described in Section 1, historical OD matrices are available to DynaMIT. These matrices are obtained from external surveys and off-line estimation.

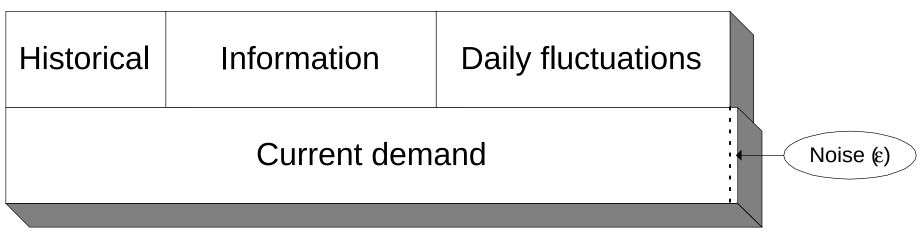


**Figure 3: Current demand**

The difference between the historical and the current demand consists of (i) the impact of today's guidance and information on drivers decisions, (ii) daily fluctuations produced by unobserved elements and (iii) a random error, which we assume to be negligible.

The role of the Demand Simulator is to transform the historical demand first into an "informed" demand, capturing the effect of information, and finally into the estimated demand reflecting daily fluctuations. The process is illustrated by Figure 4, where each row corresponds to a level of aggregation, and each column to a specific demand. It runs through six "bases". The Demand Simulation transforms historical OD matrices (base 1) into a disaggregate description of the estimated demand (base 6). The historical OD matrices are first disaggregated into an explicit list of drivers (base 2) using external socio-economic information and behavioral models capturing habitual behavior. The impact of information and guidance on drivers' decision is simulated using disaggregate behavior models to obtain informed demand at base 3. This disaggregate informed demand is in turn aggregated to the OD level (base 4). The OD estimation algorithms use data from the surveillance system to compute the difference between the aggregate representation of the informed demand (base 4) and the estimated demand (base 5). A complete list of drivers (base 6) is obtained from a final disagreggation.

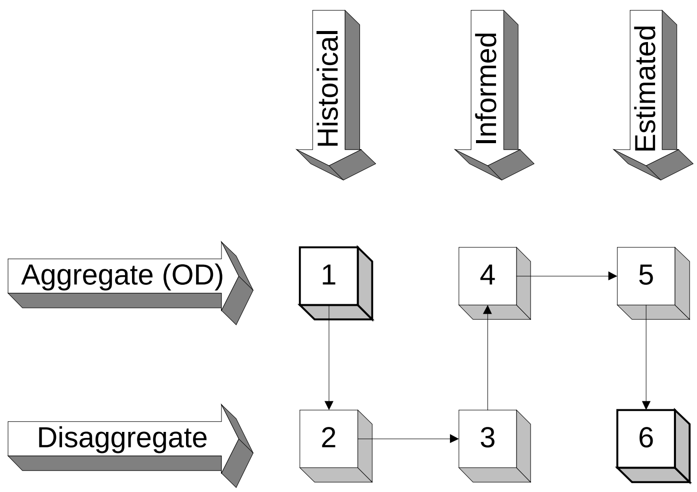


**Figure 4: Demand Simulation**

The informed demand (step 3) is obtained by applying disaggregate behavior models that capture several trip decisions including the choice whether or not to make a particular trip from origin to destination, as well as the selection of departure time, mode and route. DynaMIT models a driver's trip choice in three specific contexts:

- the usual, or habitual, choice of departure time, mode and route;
- the decision to change some aspects of the habitual choice as a response to information received prior to departing from the trip origin. This is referred to as the *pre-trip decision*; and
- the decision to change the currently-followed route in response to information received during the trip. This is referred to as the *en route decision*.

DynaMIT includes a number of disaggregate behavioral models for the above situations (Cascetta et al., 1996, Mahmassani and Liu, 1997). Each person confronted with a choice is individually represented so that the model can be applied and eventually translated into vehicle movements on the network.

The estimated demand (step 5) is obtained using statistical models aiming to replicate observed data collected in real-time from the surveillance system. DynaMIT features a dynamic OD estimation process based on a Kalman filtering algorithm and on a auto-regressive process (Ashok and Ben-Akiva, 1993). The auto-regressive process, captures the dynamic evolution in time of the state variables of the Kalman filter. It is calibrated off-line and constitutes an input to the real-time system.

Interestingly, almost the steps described in Figure 4 can be used for prediction, as historical information is available for the future as well. The only exception is the statistical models, which use data from the surveillance system to estimate OD matrices. The prediction of OD matrices, in contrast, is performed by applying an auto-regressive process to the deviations between informed and estimated OD matrices, similarly to the technique proposed by Ashok and Ben-Akiva (1993).

### *3.2 Mesoscopic Supply Simulation*

The Mesoscopic Supply Simulator uses as input the list of drivers produced by the Demand Simulator, and simulates their trips across the network. As an output, a wide range of network performance indicators are obtained including travel time, flows and densities.

The Supply Simulator combines a microscopic representation of traffic, where each individual vehicle is represented, with macroscopic models capturing the traffic dynamics. The motivation behind representing individual vehicles is the explicit modeling by the Demand Simulator of the en-route information impact on drivers' decisions. The choice of macroscopic models for traffic dynamics is mainly based on the real-time requirement performance. We briefly describe here the main components of the network representation, the basic dynamic models and the simulation process.

### 3.2.1 Network representation

The network representation consists of static and dynamic components. The static components represent the topology of the network. They consist in a set of links, nodes and loading elements. The nodes correspond to intersections of the actual network, while links represent unidirectional pathways between them. The loading elements represent locations where traffic is generated or attracted. They are a generalization of the zone centroid nodes of traditional models, because they can be either nodes or links.

The dynamic components are designed to capture some aspects of the traffic dynamics. While the characteristics of the former are fixed during the simulation, the dynamic components are continuously updated. Each link is divided into segments that capture variations of traffic conditions along the link. While most segments are defined in advance, additional segments can be dynamically created to capture the presence of incidents. Each segment has a capacity constraint at its downstream end. Depending on the nature of the segment, this capacity constraint can be due to the static physical characteristics of the road, or to the dynamic occurrence of an incident. Each segment has a moving part and a queuing part. The moving part represents the portion of the segment where vehicles can move with some speed. The queuing part represents vehicles that are queued up.

### 3.2.2 Traffic Dynamics

Traffic dynamics are captured by two major models: a deterministic queuing model and a speed model. As a matter of fact, the queuing model is a family of models. Each specific queue status (formation, dissipation, blockage, etc.) is captured by a different model. As an example, the position $q(t)$ of a given vehicle joining a dissipating queue at time $t$ is given by

$$q(t) = q(0) + l(ct-m)$$

where $q(0)$ is the position of the end of the queue at time 0, $l$ is the average length of vehicles, $c$ is the output capacity (i.e. the dissipation rate) and $m$ is the number of moving vehicles between the considered vehicle and the end of the queue at time 0. This is illustrated in Figure 6.

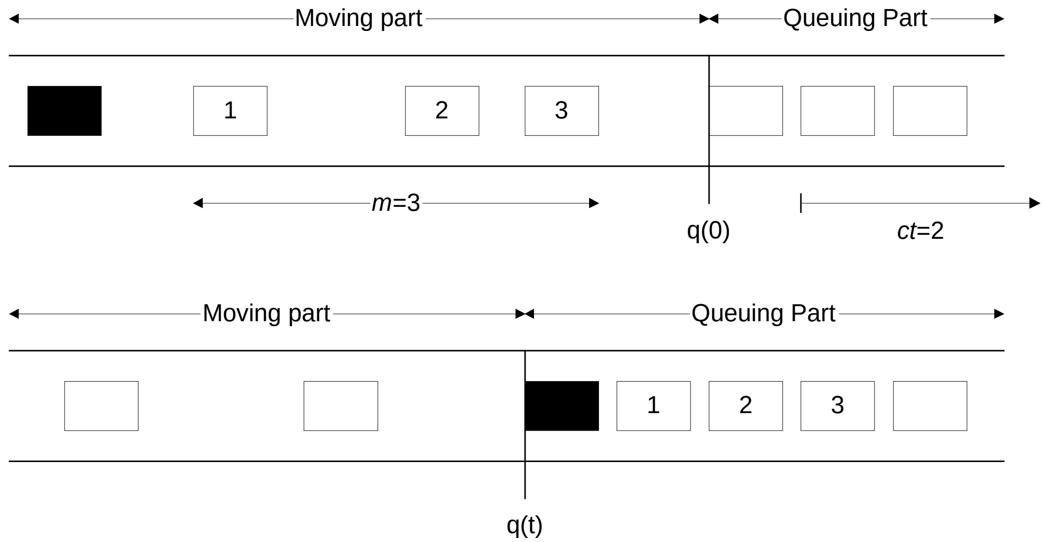


**Figure 6: Queuing model**

The speed model is based on the following assumptions. For a given moving part of a segment, two speeds are computed. The speed at the upstream end of a segment ($v_u$) is a function of the average density on the moving part of the segment. The speed at the downstream end ($v_d$) is the speed at the upstream end of the next segment. An acceleration/deceleration zone of length $\delta$ is defined at the end of the moving part. Before that zone, each vehicle is moving at a constant speed. Within the zone, the speed of vehicles varies linearly as a function of the position, as illustrated in Figure 7.

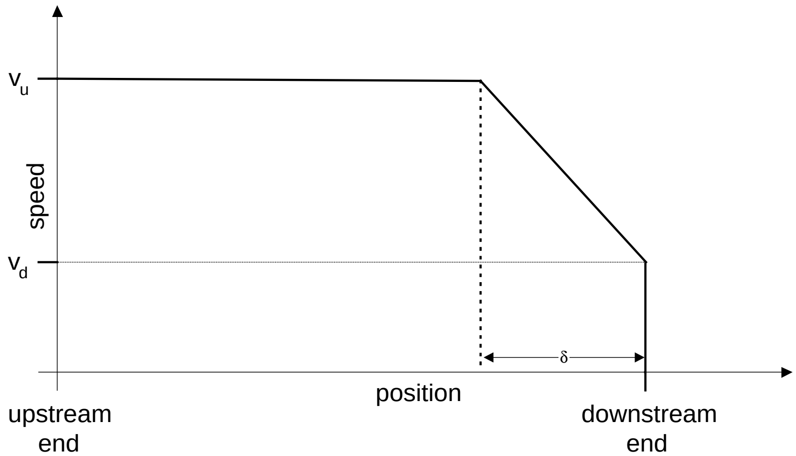


**Figure 7: Speed model**

### 3.2.3 Simulation process

The simulation of the traffic network operations proceeds in two phases: the Update Phase and the Advance Phase. The Update Phase performs most of the time consuming calculations. It is used for updating the traffic dynamics parameters (e.g. densities, speeds) used in the simulation. The Advance Phase operates at the microscopic level. It is used for advancing the vehicles to their new positions. The Advance Phase has a higher frequency than the Update Phase. The exact time discretizations, for both the Update and Advance phases, depend on each specific application and are selected to obtain the best compromise between traffic dynamics accuracy and real-time performance.

## 4. Conclusion

DynaMIT is a real time dynamic traffic assignment system that provides traffic predictions and travel guidance. To maximize the quality of the prediction, a rolling horizon framework has been implemented. It enables frequent re-estimation of the current state of the network, which is the starting point of the prediction process, to continuously exploit the real-time information collected by the surveillance system. DynaMIT contains two important simulation tools: a Mesoscopic Demand Simulator and a Mesoscopic Supply Simulator. These tools are designed such that:

- they can be used for both estimation and prediction purposes within DynaMIT,
- they combine aggregate and disaggregate traffic representation in the same framework, and
- they provide several user specified means for exploring tradeoffs between execution speeds and accuracy.

## 5. References


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