Traffic Estimation & Prediction System

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Intelligent transportation systems are being developed and deployed to improve the efficiency, productivity, and safety of existing transportation facilities and to alleviate the impacts of transportation on the environment. These systems exploit currently available and emerging computer, communications, and vehicle sensing technologies to monitor, manage, and control the highway transportation system. In addition, these systems provide various levels of traffic information and trip advisories to users, including many ITS service providers, so that travelers can make timely and informed travel decisions.

The success of many ITS subsystems—such as advanced traffic management systems (ATMS), advanced traveler information systems (ATIS), advanced public transportation systems, commercial vehicle operations, and emergency management systems—depends on the availability of timely and accurate estimates of prevailing and emerging traffic conditions. Thus there is a strong need for a traffic prediction system that uses advanced traffic models to analyze data, especially real-time traffic data, from different sources. The estimates and predictions derived from such a system can be used to select proactive strategies for meeting various traffic control, management, and operation objectives. This traffic prediction system can be regarded as a principal cognitive element of ITS residing in traffic management centers, and can form a bridge between ATMS and ATIS (Figure 1).

Dynamic Traffic Assignment

To meet the need for a traffic prediction system and to help address complex traffic control and management issues in the dynamic ITS environment, the Federal Highway Administration initiated a Dynamic Traffic Assignment research program in August 1994. The main objective of this program is to develop a deployable real-time Traffic Estimation and Prediction System (TrEPS) to meet information needs in the ITS context.

A real-time TrEPS is envisioned to be an ATMS support system that resides in traffic management centers. TrEPS will be closely related to other ATMS support systems, including systems for surveillance, traffic control, incident detection and management, and variable message sign management, as well as to other ITS subsystems, such as ATIS, advanced public transportation systems, commercial vehicle operations, and emergency management systems. Essentially, TrEPS will provide information for these systems, such as travel information for pretrip planning (i.e., travel mode, departure time, and route) and guidance to travelers for en route switching.

Dynamic Traffic Assignment is a long-term, multiphase research program. Phase I involves conducting the research required to develop a functional prototype TrEPS with established potential for real-time operations. This effort includes evaluating the prototype in a laboratory environment and at a selected traffic management center to identify real-time implementation issues. In Phase II, the prototype will be enhanced on the basis of lessons learned from the evaluation and experiments of Phase I. The system will also be further improved by the incorporation of complex ATMS and ATIS strategies, such as

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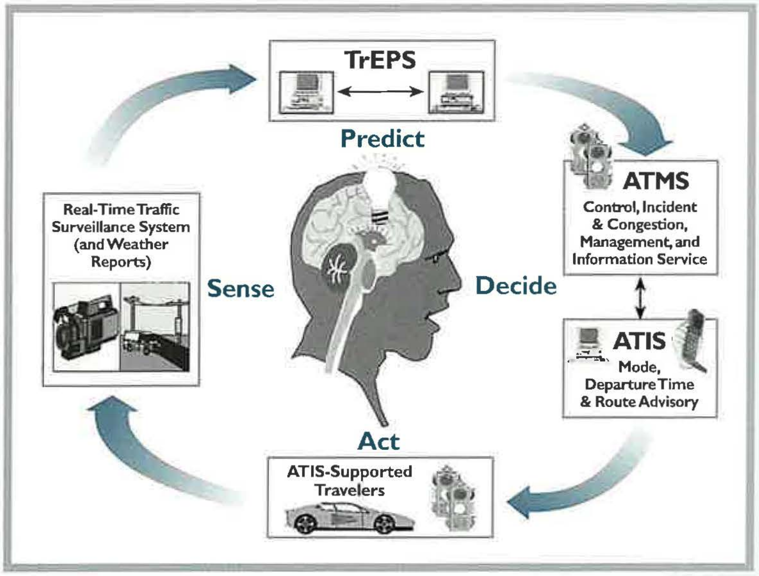


FIGURE 1 TrEPS: A principal cognitive element of ITS.

real-time traffic adaptive control systems, into the traffic estimation and prediction process.

Development of TrEPS

Oak Ridge National Laboratory (ORNL) has been designated by FHWA as manager for the development of a deployable, real-time TrEPS. The development effort will encompass three major tracks: development of TrEPS prototypes, independent laboratory evaluation, and the field experiment at the selected traffic management center.

Development of TrEPS Prototypes

Two parallel research contracts were awarded to Massachusetts Institute of Technology (MIT) and the University of Texas at Austin (UTX), respectively, in October 1995. Each team was expected to develop a prototype TrEPS that would demonstrate the system's potential for real-time application. Documents on functional requirements, system design and framework, analytical methodologies, and software development were completed in 1998. The MIT and UTX prototype TrEPS—DynaMIT and DYNASMART-X, respectively—were delivered to ORNL in October 1998 for laboratory evaluation.

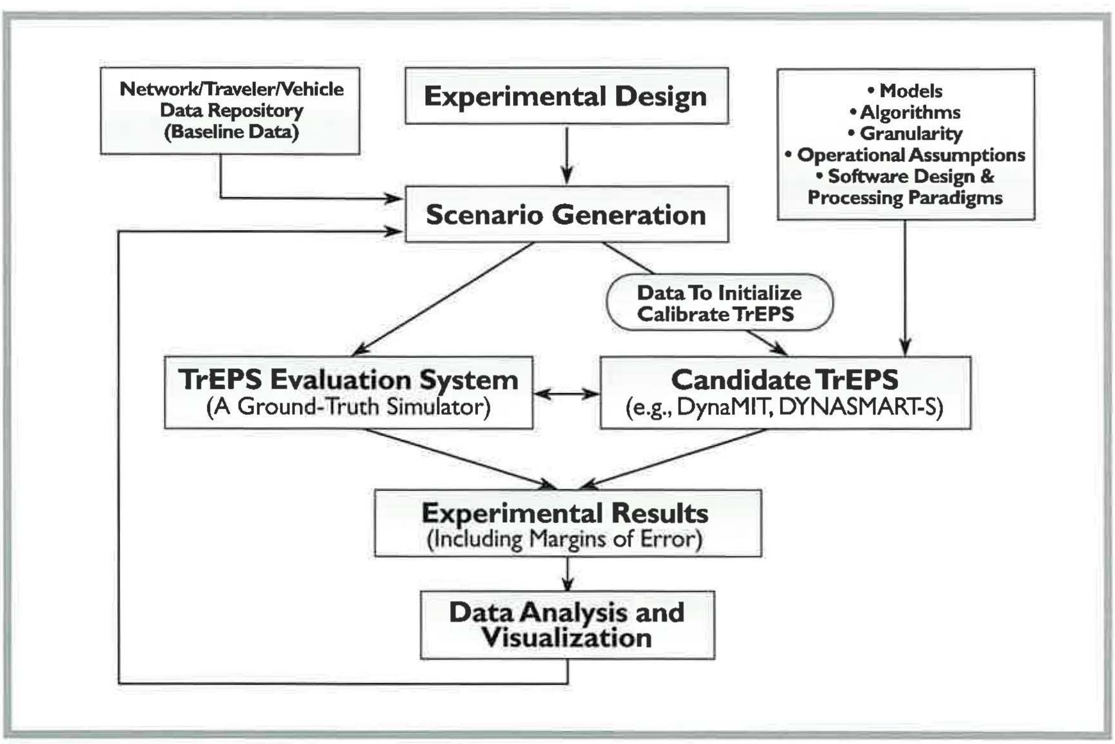
Both prototype systems use a prediction-based assignment-simulation framework. Both use distributed computing to support real-time operations, including data synchronization, self-calibration of system parameters, and self-correction of system states. The two systems are also capable of providing both *normative* and *descriptive* information for routing guidance: the former type of information gives travelers routing guidance aimed at attaining certain systemwide objectives, taking into account the long-term credibility and acceptance of the information system; the latter describes the dynamic evolution of traffic patterns spatially and temporally in large-scale networks. At their current stage of development, the two systems differ in the way they represent transportation networks and traffic in their models, in assumptions regarding driver behavior in response to ATMS and ATIS, in approaches to real-time data synchronization, and in system design and integration.

Independent Laboratory Evaluation

ORNL recently completed a laboratory evaluation of both prototype systems (see Figure 2). To assess the credibility, extendability, and real-time deployment potential of TrEPS, a comprehensive laboratory evaluation had to be performed at the functional, model, software, and system levels. All of the software and documents were thoroughly reviewed and tested

- To validate all basic functional requirements.
- To examine the robustness of the system.
- To verify that each component satisfied its design objectives.

FIGURE 2 Laboratory evaluation framework for TrEPS.



♦ To assess the operational performance of each component or function of the system in terms of accuracy, stability, operational efficiency, and robustness to input errors.

Field Experiment

The prototypes will undergo a field experiment in a traffic management center in which their functionality, prediction accuracy, computational efficiency, and robustness will be investigated. The testbed of the California Department of Transportation (Caltrans) has been selected for this purpose. The Caltrans testbed, located in Santa Ana, California, is the center for the collection of all traffic data in Orange County. Sensors placed throughout the Orange County freeway network record real-time speeds and other traffic parameters, while surveillance cameras at key locations in the network allow visual inspection of traffic patterns. The data thus collected are sent back to the traffic management center, along with reports regarding accidents, road closures, and construction. The data are used by the traffic management center operators to adjust the signal timing for traffic lights and ramp meters throughout the area, and to display information on variable message signs that are visible from the road network.

The following three tests will be performed during the field experiment:

♦ **Open-loop off-line evaluation** will be used to investigate issues related to traffic prediction capability, data quality, modeling, and system functionality. In addition, calibration of TrEPS submodels using off-line data will allow any online evaluation process to proceed more smoothly. Since this will be an open-loop test, traffic information predicted by TrEPS will not be implemented at the traffic management center in any fashion.

♦ **Closed-loop off-line evaluation** will be conducted in a laboratory environment using the archived field data. A traffic simulator will be used to represent the real-world data and to interact with TrEPS in a closed-loop fashion. Traffic information generated by TrEPS will be passed to and implemented in the simulator, making it possible to evaluate the system's traffic prediction capability, as well as to investigate the effect of implementing the information. This test will also enable examination of algorithms for information generation, although there may be some complexity associated with calibrating the traveler behavior models and vehicle movements in the simulator using the offline dataset.

♦ **Open-loop online evaluation** involves feeding surveillance data from the testbed directly into TrEPS. For this purpose, real-time data must be transformed into input files consistent with the TrEPS architecture. As with the open-loop off-line evaluation, this test will make it possible to observe the efficiency and proposed information strategy of the system without actual distribution of information to travelers.

Applications

TrEPS may be used within ITS deployments in three principal ways. First, on a daily basis, the system will provide information that will aid in the making of intelligent decisions by travelers and ITS service providers. This daily role as an information provider is recognized in the market packages for many traffic and transportation applications,[1] as indicated in a series of reports published by the U.S. Department of Transportation (*1*). Since market package ATMS09, Traffic Network Performance Evaluation, is essentially a TrEPS, any ITS deployment that incorporates this package is a TrEPS-based deployment. Market package ATIS06, Integrated Transportation Management Route Guidance, explicitly incorporates the system as well. Other market packages that do not explicitly refer to TrEPS will achieve their ultimate effectiveness only when they utilize information generated by the system.

A second application of the system is to facilitate interjurisdictional, interservice operations within a large area. The Regional Traffic Control market package was defined to allow these kinds of operations through the sharing of traffic data. TrEPS extends this concept by facilitating coordination through the sharing of projected traffic conditions. The projected conditions are based on the plans of the various jurisdictions and services, and are updated to reflect the responses of each group to the others' plans, as well as current traffic conditions. Such operations can involve the coordination of many market packages. For example, TrEPS could be used to respond in real time to a serious incident involving hazardous materials by supporting and coordinating the following packages:

♦ Integrated Transportation Management Route Guidance
♦ Incident Management
♦ Emergency Response
♦ Emergency Vehicle Routing
♦ Dynamic Route Guidance

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1 "Market packages" are architecture-compatible ITS building blocks that allow decision makers to deploy architecture-compliant ITS subsystems incrementally.

- ♦ Surface Street Control
- ♦ Freeway Control
- ♦ Lane Management
- ♦ Demand-Response Transit Operations
- ♦ Multimodal Coordination
- ♦ Fleet Administration
- ♦ HAZMAT Management

Finally, TrEPS can be used for transportation planning. The system could be useful in many planning contexts, such as time-varying traffic demand and network conditions, modeling of ITS strategies, and explicit representation of oversaturation and traffic queues. With these capabilities, planners should be able to produce more reliable results than those generated by the current static traffic assignment techniques for determining the best transportation alternative. The improved traffic assignment component of TrEPS is also expected to have application in the ITS Deployment Analysis System to help assess ITS options.

Less obvious are the implicit functional and design linkages between TrEPS operation and other market packages. Examples are Network Surveillance, Probe Surveillance, Incident Detection System, and Advanced Vehicle Control.

Issues

To obtain feedback on TrEPS from both researchers and practitioners, the Transportation Research Board's Committee on Traffic Flow Theory and Characteristics sponsored two technical sessions at TRB's Annual Meeting in 1999. Several issues raised during these sessions will be addressed as development of the system proceeds.

Data Availability. TrEPS requires a large amount of data at a very detailed level—such as network geometry, traffic control, traffic demand, surveillance, and traveler information—to represent network traffic and control scenarios and to calibrate parameters. Because of the limited coverage of surveillance equipment, some data collected from the field may be incomplete for modeling purposes. Other data, such as time-varying origin–destination information, may be difficult to obtain.

Inconsistent Model Representation. In the traffic research and engineering communities, standard definitions are lacking for many elements, such as network geometry, traffic operational characteristics, signalization, traffic flow, ITS services and products deployed, and driver characteristics and behavior dynamics. As a result, representation of these elements in modeling may vary, making communication between different traffic models difficult. The two prototype TrEPS, DynaMIT and DYNASMART-X, are examples of this limitation. Therefore, development of consistent traffic engineering terms and definitions is essential. It may be hoped that current work of ITS America and the Institute of Transportation Engineers on a Traffic Management Data Dictionary and Traffic Software Data Dictionary, respectively, will meet this need.

Margin of Error. There is a trade-off between the accuracy of the model results and the amount of data required to run TrEPS. It is important to define the acceptable margin of error in the system's forecasts of both traffic demand and network conditions. For example, is it necessary to have snapshot-in-time data for model calibration and validation, or are various kinds of average or approximate data acceptable? Data collection is expensive, and data computation is time-consuming. Answers to these questions are therefore critical, and they may be application-specific as well.

Granularity (Time and Spatial Resolutions). Like the amount of data, levels of granularity in time and space are critical to the accuracy of model results and the resources required. For example, how dynamic do the data have to be in terms of simulation time step, prediction roll interval, and prediction period? How micro must the data be in terms of network level of detail, vehicle attributes, aggregation of vehicles, and representation of traffic flow behavior?

Integration with Existing Planning Models. Traditional static traffic assignment models used in the transportation planning process cannot address complex issues associated with dynamic transportation networks. Since TrEPS is designed specifically to deal with this problem, it can be used to improve the traffic assignment techniques employed in current models. To this end, TrEPS must be fully integrated with existing regional travel demand models. The interface control document recently completed by ORNL will help achieve this integration.

Traveler Behaviors. To provide accurate traffic information, TrEPS must address the issue of traveler behavior and capture travelers' responses to various transportation control strategies. Pretrip planning (e.g., departure time and route choice) and en route switching are currently modeled in the system. However, the models for these behaviors were calibrated with limited laboratory data. Data from the field are needed to calibrate and validate these models.

Real-Time Implementation. A real-time deployment of TrEPS would likely involve a number of complex technical issues, including:

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