A ROADMAP

FOR THE RESEARCH, DEVELOPMENT AND DEPLOYMENT OF

TRAFFIC ESTIMATION AND PREDICTION SYSTEMS FOR REAL-TIME AND OFF-LINE APPLICATIONS (TREPS, TREPS-P)

BY HENRY LIEU

Travel Management Team

Office of Operations RD&T

Federal Highway Administration

March 2003 (Revised Version)

Created on 6/5/03 5:52 PM

Table of Contents

1 INTRODUCTION

This document provides a Roadmap for the Federal Highway Administration's (FHWA) Dynamic Traffic Assignment (DTA) research project. FHWA established the DTA Project to develop a deployable, real-time Traffic Estimation and Prediction System (TrEPS). The system will be capable of estimating and predicting traffic information for real-time traffic management and control purposes and to meet the information needs in the Intelligent Transportation Systems (ITS) context. The project will also leverage the same technology to develop a new generation of tools to support transportation network planning and traffic operations and control decisions within the ITS environment. In this context, the paper discusses

- The DTA project
- TrEPS role in the FHWA's strategic goals
- TrEPS role in the national ITS architecture
- TrEPS and TrEPS-P users
- Roadmap for research, development and deployment of TrEPS and TrEPS-P
- Benefit potential

Detailed information about TrEPS and TrEPS-P development can be found in the references or the project reports.

2 THE DTA PROJECT

Intelligent Transportation Systems (ITS) are being developed and deployed to improve the efficiency, productivity, and safety of existing transportation facilities and to alleviate the impact of transportation on the environment. These systems exploit currently available and emerging computer, communication, and vehicle-sensing technologies to monitor, manage, and control the highway transportation system. They also provide various levels of traffic information and trip advisory to system users, including many ITS service providers, so that travelers can make timely and informed travel decisions.

The success of ITS deployment depends on the availability of advanced traffic analysis tools to predict network conditions and to analyze network performance in the planning and operational stages. Many ITS sub-systems, especially Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS), Advanced Public Transportation Systems (APTS), Commercial Vehicle Operations (CVO), and Emergency Management Systems (EMS), are heavily dependent on the availability of timely and accurate wide-area estimates of prevailing and emerging traffic conditions. Therefore, there is a strong need for a Traffic Estimation and Prediction System (*TrEPS*) to meet the information requirements of these sub-systems and to aid in the evaluation of ITS traffic management and information strategies.

The FHWA R&D initiated a Dynamic Traffic Assignment (DTA) research project in 1994 to meet these data needs and to address complex traffic control and management issues in the information-based, dynamic ITS environment. Under this project, Oak Ridge National Laboratory (ORNL) was designated as the manager for the development of a deployable, real-time TrEPS as well as an offline, planning version (TrEPS-P). In October 1995, two contracts were awarded to teams from the University of Texas at Austin (UTX) and the Massachusetts Institute of Technology (MIT) to develop these systems for use in ITS environments.

2.1 DTA Objectives

The DTA Project is dedicated to two primary objectives:

- To develop a deployable real-time TrEPS to meet information needs in the ITS context
- To leverage the same technology to develop a new generation of tools to support transportation network planning and traffic operations and control decisions within the ITS environment

2.1.1 TrEPS Functions

Real-time TrEPS is an ATMS and ATIS support system that will reside in Traffic Management Centers (TMCs). TrEPS will interact with ATMS, ATIS, surveillance systems, incident management systems, and other ITS sub-systems. It provides predictive traffic information to ITS sub-systems to help generate proactive, network-wide, coordinated guidance and control strategies. It also generates travel information for pre-trip planning (i.e., travel mode, departure time, and route) and other traffic information and guidance to travelers for en-route diversion. As shown in Figure 1, TrEPS is a cognitive element in ITS and connects the traffic surveillance systems and ITS sub-systems.

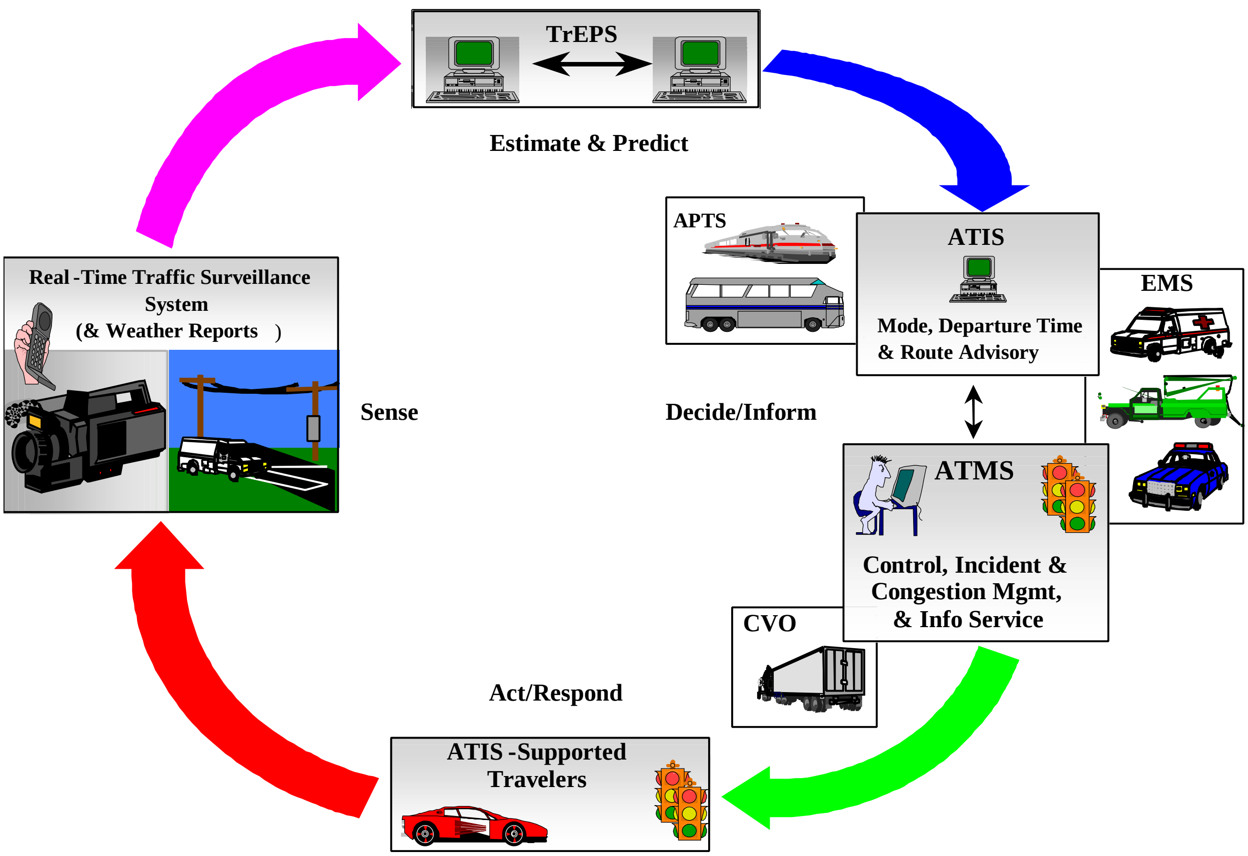

Figure 1. TrEPS: A "bridge" and a cognitive element for ITS sub-systems.

TrEPS utilizes advanced traffic models, surveillance information, various historical data, and information from other ATMS and ATIS support systems to provide the following broad functional capabilities:

- Estimating and predicting (short term) traffic OD demand for traffic control and management
- Estimating and predicting traffic conditions
- Providing travel mode, departure time, route, and other traffic information and advisory to travelers through ATIS for meeting various traffic management and control objectives
- Interacting with other ITS sub-systems or, in the interim, interfacing with other ATMS support systems within the TMCs and with ATIS

Figure 2 provides a generalized framework for a TrEPS prototype.

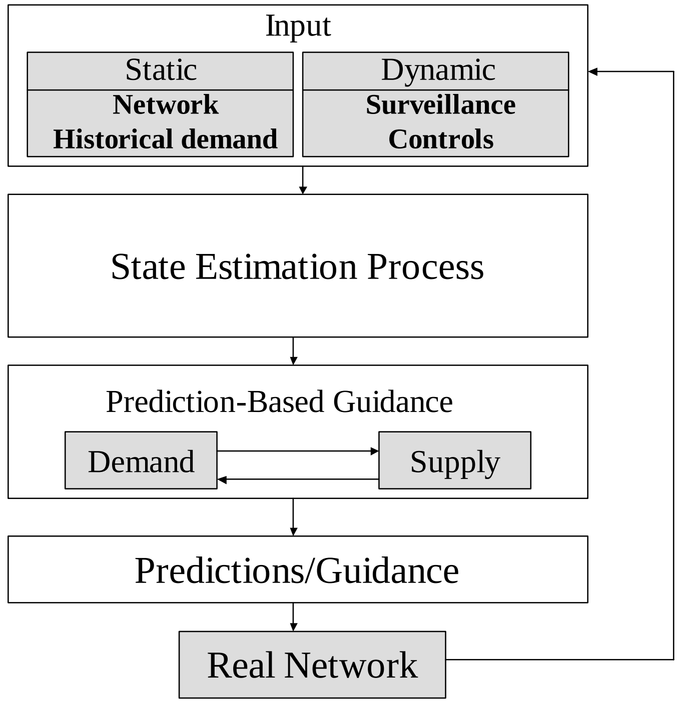

Figure 2. Generalized TrEPS Framework

2.1.2 TrEPS Applications

TrEPS can be applied in the following areas in both real-time and off-line operational modes:

- Providing predictive real time traffic information at TMC's for generating proactive ATIS and ATMS control strategies
- Providing traffic information to emergency vehicles and Information Service Providers (ISP) for route guidance
- Providing off-line traffic operations evaluation by integrating with a simulator or archived TMC data
- Assessing impacts of different ATMS and ATIS strategies on the highway network performance
- Evaluating congestion pricing schemes that vary with location, time, and prevailing roadway conditions
- Synthesizing origin-destination data for planning analysis

2.1.3 TrEPS-P Functions

One of the objectives of TrEPS development is to leverage the same technology to develop a new generation of tools to support transportation network planning and traffic operations and control decisions within the ITS environment. TrEPS-P represents a new generation of tools, which supports these functions. This tool combines (1) dynamic network assignment models, used primarily in conjunction with demand forecasting procedures for planning applications, and (2) traffic simulation models, used primarily for traffic operational studies. TrEPS-P provides the capability to (1) predict day-to-day evolutions of travel demand and network conditions, (2) predict within-day patterns of traffic flows and travel times, and (3) compare different design, operations, and management alternatives. Figure 3 provides a generalized framework for the TrEPS-P prototypes.

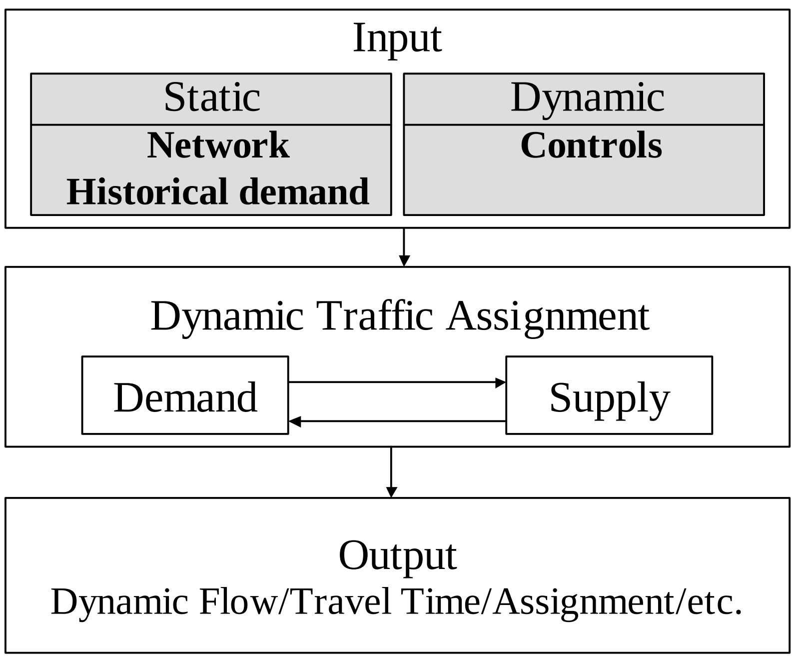

Figure 3. Generalized TrEPS-P Framework

TrEPS-P provides the following functions:

- TrEPS-P describes the evolution of traffic flows in a traffic network that result from the travel decisions of individual trip-makers at different locations in a network over a given period of time.

- TrEPS-P supports the evaluation of strategic and tactical planning decisions by identifying deficiencies in design and evaluating the impact of alternative courses of actions in the context of the broader set of policy objectives for the study area.

Note: TrEPS-P is a planning version of TrEPS, in which the OD data is input externally and is fixed for the analysis period. However, for TrEPS, the OD data used for network evaluation is internally estimated in the model based on the surveillance data, historical OD data, and drivers' responses to the traffic control strategies.

2.1.4 TrEPS-P Applications

TrEPS-P can be applied in the following areas for off-line operation analyses and planning analyses:

- Providing dynamic traffic assignment methods for transportation planning analysis. TrEPS-P can be readily introduced at the traffic assignment stage of the widely used four-step planning process to replace the existing static traffic assignment procedures

- Assessing impacts of the ITS and non-ITS technologies on the transportation network in the planning process

- Supporting decision-making for work zone planning and traffic management

- Assessing impacts of different traffic operation and control strategies with fixed OD demand for the analysis period

3 TREPS'S ROLE IN THE FHWA'S STRATEGIC GOALS

The FHWA's vision is "to create the safest, most efficient and effective highway intermodal transportation system in the world for the American people…where crashes, delays, and congestion are significantly reduced…freight moves easily and at the lowest costs across towns, States, and international borders…roads protect ecosystems and where travel on our roadways does not degrade the quality of the air…" To fulfill this vision, FHWA has identified five strategic goals:

- *Safety*
- *Mobility*
- *Productivity*
- *Human and Natural Environment*
- *National Security*

TrEPS and TrEPS-P will help FHWA meet their strategic goals, especially in the areas of mobility and productivity. These systems will, directly or in conjunction with other ITS systems, reduce congestion and delays in cities and transportation corridors, thereby increasing personal mobility, productivity, and competitiveness, decreasing environmental impacts, increasing safety, and improving quality of life

4 TREPS ROLE IN THE NATIONAL ITS ARCHITECTURE

The Department of Transportation (DOT) sponsored the development of an extensive, comprehensive National ITS Architecture to promote the deployment of cost-effective Intelligent Transportation Systems that are interoperable and uniform (ITS America, *The National Architecture for ITS* 1999). The National ITS Architecture promotes interoperability while providing the freedom of choice required by decision makers to meet diverse deployment needs (based on the needs of constituents, regions, and organizations). This architecture is complex, abstract, and provides for the "extreme variability in deployment in different areas of the nation at different times" (see *The National Architecture for ITS*, Implementation Strategy 1-1).

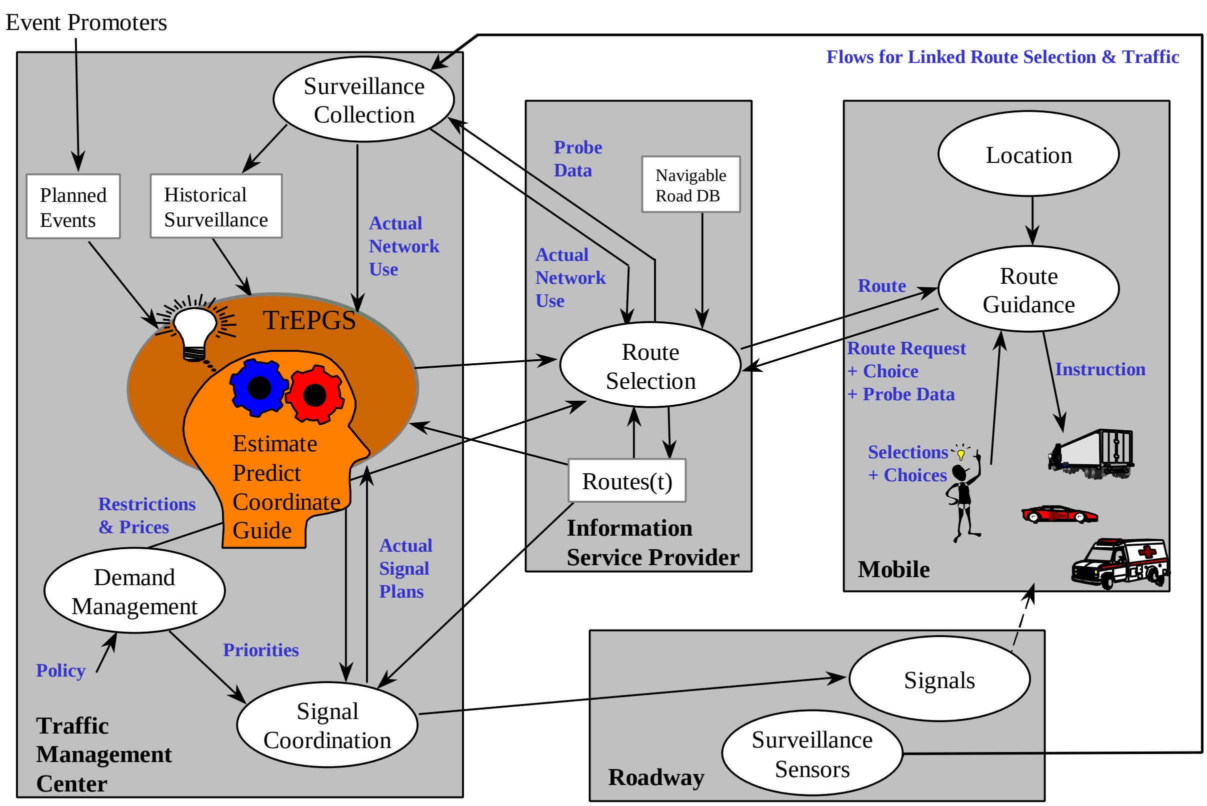

Figure 4. TrEPS role in the National ITS Architecture.

The National ITS Architecture recognizes the need for TrEPS. The ITS process requirements that were identified in the architecture development are recorded in the ITS Logical Architecture, which is based on an initial set of user requirements provided by the stakeholder community. These initial requirements were refined into a set of derived requirements that are expressed in terms of necessary ITS component processes. The physical connections between these component processes are represented by data flows within Data Flow Diagrams (DFDs). Figure 4 provides an overview of TrEPS' role in the National ITS Architecture.

A set of more than 50 architecture-compatible ITS building blocks (called market packages) were identified to enable decision makers to incrementally deploy architecture-compliant ITS subsystems. Applications that use federal funds and involve ITS deployments are discussed in terms of these building blocks or market packages. The Traffic Network Performance Evaluation Package (market package ATMS09) described in the implementation plan is a TrEPS, and many other market packages rely on or interact with TrEPS to some extent. The ITS logical architecture requires predictions of traffic demand and traffic conditions. These requirements are the same as the functional requirements for TrEPS. The logical architecture also shows a number of other ITS processes making use of the predictive information produced by TrEPS. Thus, TrEPS is the foundation upon which other ITS market packages are deployed (Figure 5).

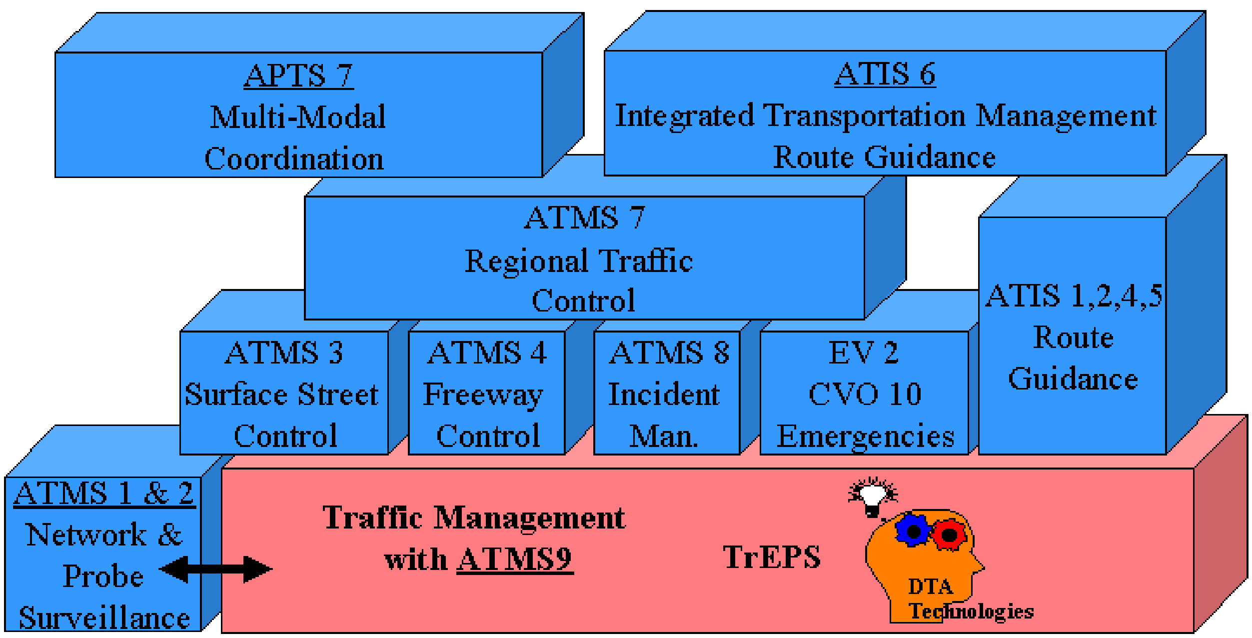

Figure 5. TrEPS is the foundation for many ITS market packages.

The National ITS Architecture recognizes that many of the required ITS subsystems (processes) will rely upon predictive information produced by TrEPS. This includes processes such as Travel Demand Management, Route Selection, and Traffic Control, as well as users such as traffic operations personnel. Under the heading of "Provide Traffic Surveillance" (DFD 1.1), the National ITS Architecture states that

> Predictive data is used to develop travel demand and routing strategies.

Many ITS functions use the current, long-term, and predictive data stores as a source of traffic data.

Traffic operations personnel can display current, long-term, and predicted data.

- The description of the Demand Management Functions states, “The ITS architecture can support the long-term predictive models upon which congestion pricing decisions can be made.”

The architecture also provides support for other functions that can use predictive information, including CVO, APTS, and EMS support. Figure 6 provides an overview of the use of TrEPS within other ATMS subsystems in a TMC environment. Transit service providers will be able to use predictive information to locate nearest access points, determine costs, and predict travel times. Public leaders will be able to use predictive information to improve public safety. Police, fire, and emergency service providers, who are finding it increasingly difficult to respond to roadway or other emergencies due to traffic congestion, will be able to use TrEPS-based information to more effectively locate and respond to traffic accidents with proper staffing and equipment, saving time, resources, and, possibly, lives.

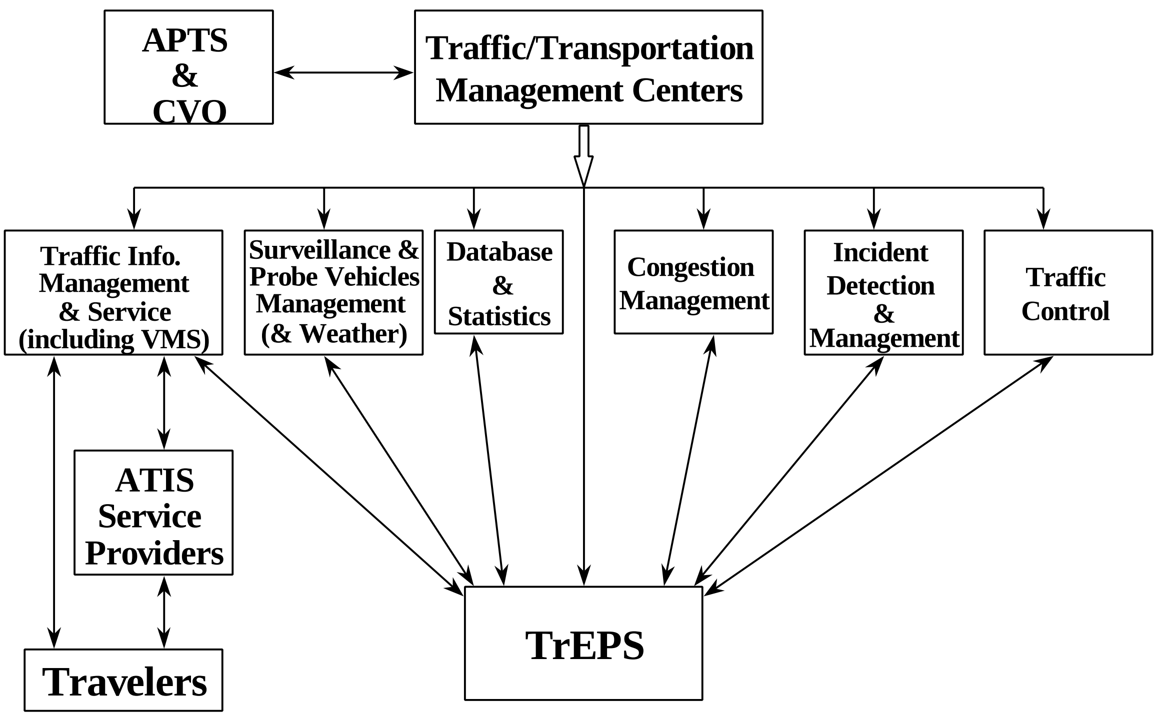

Figure 6. TrEPS’ Role within ATMS subsystems in a TMC environment.

5 TREPS AND TREPS-P USERS

TrEPS is required for deployment of major ITS technologies, provides crosscutting functionality, and serves multiple stakeholders. TrEPS and TrEPS-P will have six primary user groups:

- TMCs can use TrEPS to predict traffic information to Implement proactive real-time traffic management and control strategies
- Planners in MPOs can use TrEPS to synthesize O-D data and use TrEPS-P to produce more realistic traffic assignment results for planning analyses
- Coordinators can use TrEPS to facilitate multi-jurisdictional, multi-service responses to real-time traffic conditions or other activities that may be hindered by congested traffic conditions
- Information Service Providers can translate the real time traffic data into information for route guidance
- Researchers can explore innovative ATMS/ATIS strategies based on the advanced traffic flow theories and emerging computer and traffic surveillance technologies
- Traffic Engineers will be able to evaluate different traffic control strategies

Each of these user groups and applications is discussed in the following subsections. In addition to these primary users and applications, additional TrEPS applications result from the implicit functional and design linkages between TrEPS and market packages such as Network Surveillance, Probe Surveillance, Incident Detection Systems, Congestion Pricing, Advanced Vehicle Control, and Automated Highway Systems.

5.1 TrEPS in TMCs: Daily Wide-Area Operations

The National Architecture for ITS published by the US Department of Transportation (ITS America 1999) envisions TrEPS’ primary role within TMCs as a real-time information provider for ITS subsystems, such as ATMS and ATIS—TrEPS actually provides some basic ATMS and ATIS capabilities itself. Its principal function will be to estimate current traffic conditions and predict consistent emerging conditions so that TMCs can implement proactive traffic management strategies in real-time.

5.2 TrEPS-P for Transportation Planning

TrEPS-P can be used to replace the existing static traffic assignment methods in the traditional transportation planning process. This system is appealing in many planning contexts, such as time-varying traffic demand, time-varying network conditions, modeling ITS strategies, and explicit representation of over-saturation and traffic queues. Figure 7 provides an example using TrEPS-P for traffic assignment in the planning process.

With these capabilities, planners should be able to determine the best transportation alternatives more reliably than by using current traffic assignment techniques that are static in nature. Also, the improved dynamic traffic assignment component in TrEPS might be used in ITS Deployment Analysis System (IDAS) to help assess ITS deployment options.

Another potential application of TrEPS-P is for work zone traffic management. In this context, highway construction and maintenance contractors may also use the system to schedule and sequence their activities so that congestion and safety risks are minimized.

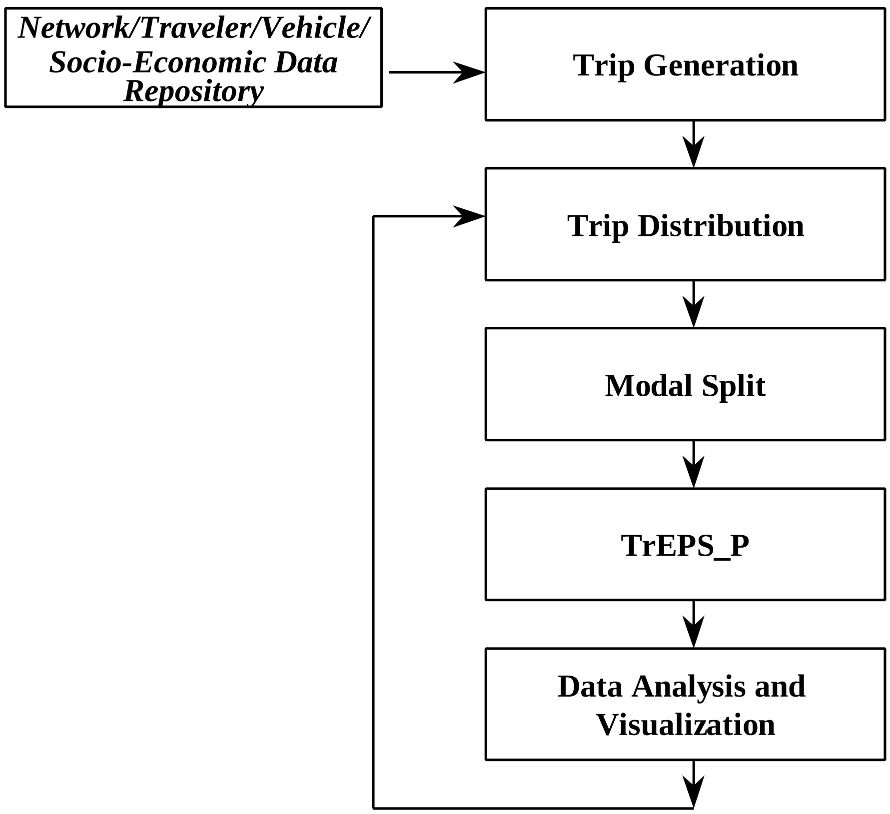

Figure 7. TrEPS-P is part of the transportation planning process.

5.3 Multi-Jurisdictional, Multi-Service Operations Coordinators

TrEPS can be used as a tool to facilitate integrated inter-jurisdictional, inter-service, wide-area operations. The “Regional Traffic Control” 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 predicted traffic conditions. These predicted traffic conditions are based on the planned response of each jurisdiction and service, and they are updated as each group responds to the other groups’ plans as well as to current traffic conditions. Such operations can involve the coordination of many 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 market packages:

- Integrated Transportation Management Route Guidance
- Incident Management
- Emergency Response
- Emergency Vehicle Routing
- Dynamic Route Guidance
- Surface Street and Freeway Control
- Lane Management
- Demand Response Transit Operations
- Multi-Modal Coordination
- Fleet Administration
- FAZMAT Management

5.4 Information Service Providers (ISP)

Information service providers will be able to translate the predictive real-time traffic data into travel information or advisory for route guidance in the ATIS context. This travel information can be used for vehicle en-route diversion to by-ass the congested area and for pre-trip planning to determine the mode, departure time, and route of the trip.

5.5 Researchers

Researchers will be able to explore and develop innovative ATMS/ATIS strategies based on the advanced traffic flow theories and emerging computer and traffic surveillance technologies. Development of Adaptive Control System (ACS*)* models and algorithms is an example.

5.6 Traffic Engineers

With TrEPS and TrEPS-P, traffic engineers will be able to evaluate a variety of advanced ITS or traditional traffic control strategies in a simulated environment in a very cost-effective way. Furthermore, since TrEPS and TrEPS-P can better address dynamic issues in the modern transportation network, it is believed that both TrEPS and TrEPS-P can produce better results for traffic engineers to conduct analysis.

6 ROADMAP FOR THE RESEARCH, DEVELOPMENT, AND DEPLOYMENT OF TREPS AND TREPS-P

In developing the National ITS Architecture, FHWA recognized that advanced ITS deployments would require the use of TrEPS functionality. FHWA understood that these advanced information processing systems would be needed to generate the estimates and predictions of traffic conditions that would be the basis of the intelligent, proactive decisions made by travelers and ITS service providers.

To meet the need for a traffic estimation and prediction system and to help address complex traffic control and management issues in the information-based dynamic ITS environment, FHWA initiated a Dynamic Traffic Assignment (DTA) research project in June 1994. Oak Ridge National Laboratory (ORNL) was designated by the FHWA as the manager for the development of a deployable, real-time TrEPS under the DTA research project. The main objective of this research project 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 TMCs. TrEPS will have close relations with other ATMS support systems, including surveillance systems, traffic control systems, incident detection and management systems, variable message sign management systems, and other ITS sub-systems (e.g., ATIS, APTS, CVO, and EMS). TrEPS will function as an information provider for these systems and could also generate travel information for pre-trip planning (i.e., travel mode, departure time, and routes) and other traffic information and guidance to travelers for en-route diversion.

The DTA research project is a long-term, multiple-phase research project. Figure 8 gives an overview of the project phases and the main activities for each phase. (Note that specific tasks under Phases 2B and 3B (dashed boxes) will be planned and budgeted on a project basis.)

The following activities were undertaken before the TrEPS development work (Phase 1) started in October 1995:

- Held a DTA pre-proposal workshop in Chantilly, Virginia in May 1994 to receive inputs from the professional community to ensure that critical DTA issues would be covered in the Request for Proposal (RFP)
- Developed the final RFP based on the inputs from the workshop participants
- Evaluated proposals and
- Awarded two contracts to Massachusetts Institute of Technology (MIT) and the University of Texas at Austin (UTX), respectively, in October 1995

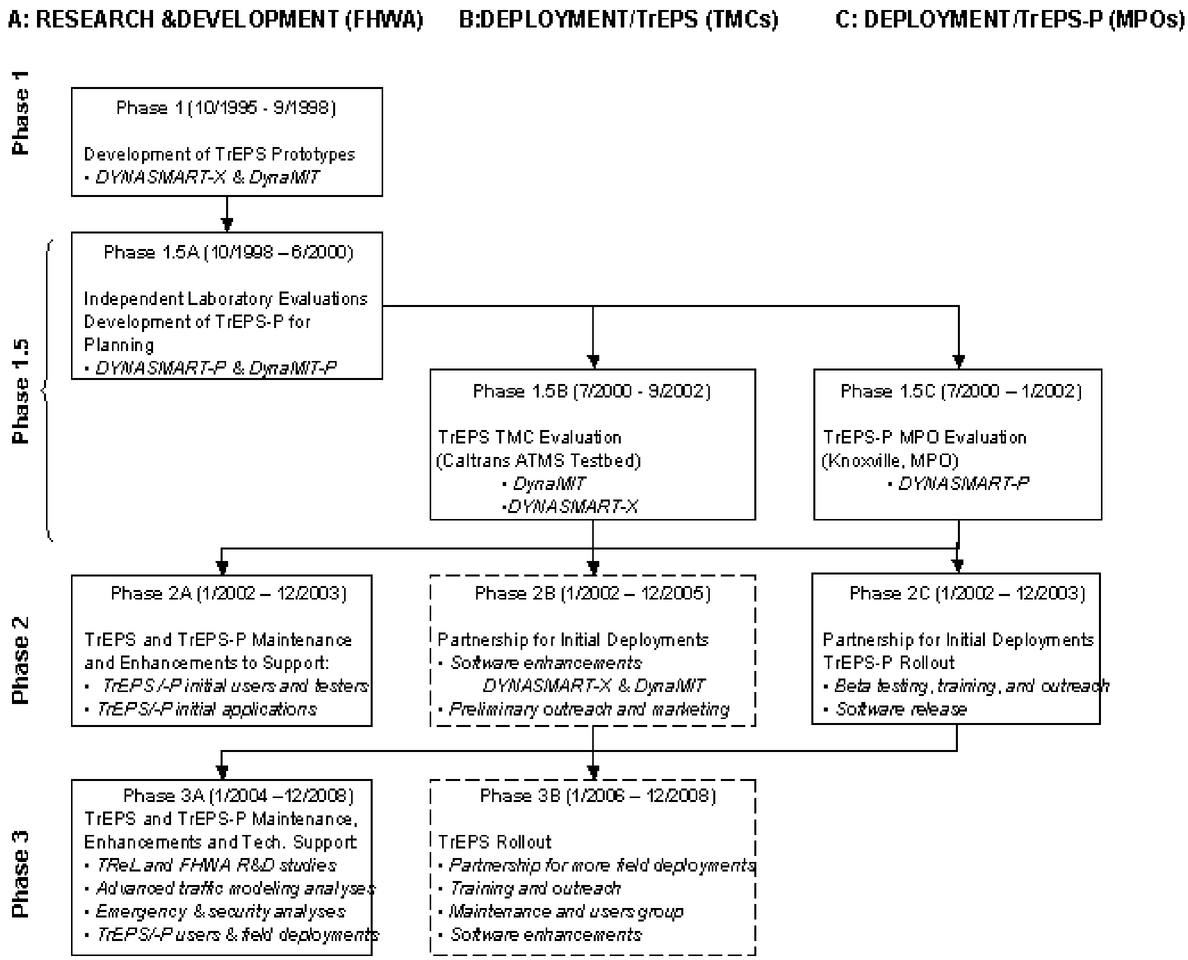

Figure 8. DTA Project Multi-phase, Multi-track Development and Deployment Plan

6.1 Phase 1 – Development of Prototype TrEPS

Phase 1 work (spanning 1995-98) is to develop a functional prototype TrEPS with established potential for real-time operations. Under Phase 1, UTX and MIT each developed a candidate TrEPS prototype. Phase I TrEPS development was completed in October 1998. Two prototype TrEPS were delivered to ORNL for evaluation: DynaMIT, developed by MIT, and DYNASMART-X, developed by UTX.

The prototypes developed by the two teams differ in terms of aggregation of characteristics of the transportation networks, traffic flow, models, algorithms, assumptions regarding driver behavior in response to ATIS and ATMS, approaches to real-time data fusion, synchronization, and system design and integration.

6.2 *Phase 1.5A: Independent Laboratory Evaluation and TrEPS-P Development*

Performance Period: 10/1998 – 6/2000.

Phases 1.5A, 1.5B, and 1.5C are independent evaluation phases. Phase 1.5A consists of a laboratory evaluation of the TrEPS and TrEPS-P prototypes from MIT and UTX - four systems in all. After the laboratory tests, the TrEPS prototypes will be field-evaluated in a TMC environment (Phase 1.5B), and the TrEPS-P prototypes will be evaluated for transportation planning and work zone applications (Phase 1.5C).

Phase 1.5A is to evaluate the prototypes and to determine if the prototypes meet all of the twenty-two functional requirements listed in the RFP. One of the 22 functional requirements for the TrEPS prototypes was that the prototypes must be able to run off-line for planning application. The importance of this capability has increased over the course of the project. As a result each of the development teams has also delivered an offline version of TrEPS for planning (TrEPS-P). These prototypes were derived from their respective real-time counterparts but have some expanded output and statistical analysis capabilities necessary for planning studies.

6.2.1 Phase 1.5A: Software Acceptance and Functional Evaluation

The software acceptance and functional evaluation will assess the software quality, credibility, functionality, extendibility, real-time deployability, and applicability of TrEPS and TrEPS-P prototypes. A comprehensive laboratory evaluation will be performed at the functional, model, software, and system levels; all of the software and associated documents will be thoroughly reviewed and tested. The objectives of the laboratory evaluation are:

- To evaluate the software systems in terms of software design and implementation details
- To verify that all basic functional requirements are met
- To examine the robustness of the systems
- To verify that each component satisfies its design objectives
- To assess the operational performance of each component or function of the systems in terms of accuracy, stability, operational efficiency, and robustness to input errors

To accomplish the objectives, the following specific tasks will be performed:

- *Inspect Software Design and Functionality* – to determine the extent to which the TrEPS prototypes (i) meet the functional requirements established in the original RFP; (ii) are well documented and maintainable; (iii) use sound architectural design; (iv) use theoretically sound modeling methods; (v) use sound programming practices; (vi) are computationally efficient; and (vii) efficiently use data storage capacity and other computer resources

- *Compare Two Prototypes* – to compare the two prototypes in terms of software design, model capabilities, etc.

- *Develop TMC Evaluation Plan* – to develop a draft plan for field evaluation of TrEPS to address the potential real time implementation and operation issues

- *Refine TrEPS and Prepare Final Report* – to refine TrEPS based on the evaluation results and develop a report summarizing the evaluation findings and recommendations

- *Perform Benchmark Evaluation* – is to evaluate the prototypes under a common set of scenarios in a simulation environment. This will provide a more direct method of comparing the two prototypes against one another and against ground truth

- Develop a stand-alone version for planning, TrEPS-P

All tasks defined in the Phase 1.5A: independent laboratory evaluation plan, except for the benchmark evaluation were completed by June 2000.

More detailed description regarding the software acceptance and functional evaluation plan can be found in the ORNL's Phase 1.5 Plan entitled Independent Laboratory Evaluation of Dynamic Traffic Assignment Systems (Version 1.2), April 25, 1999

6.3 Phase 1.5B: TrEPS Field Experiment at a TMC

Performance Period: 7/2000 – 9/2002

The laboratory testing and evaluation of TrEPS does not preclude field-testing. Rather it serves to provide guidance to the more costly field operational tests. Costly errors and mistakes can be avoided through comprehensive laboratory tests. Nevertheless, field evaluations are required to ensure the ultimate applicability and deployability of the TrEPS. A first step toward a full-scale field evaluation is to evaluate the candidate TrEPS in a TMC environment. Partnerships will be established so that the prototypes can be evaluated in a TMC environment. Currently, Caltrans ATMS test bed in Orange County, CA, has been selected as a test site for this study.

The main tasks of the TMC evaluation will be to:

- Assess the quality of the estimation and prediction capabilities using real data

- Assess benefits and applicability of the outputs generated from TrEPS for TMC operations

- Assess the deployment viability of TrEPS in TMCs

- Identify the real-time operational and implementation issues that should be further addressed under Phase 2 TrEPS development
- Assess the offline benefits and applicability of the TrEPS output in the transportation planning process, i.e., generation of synthetic OD using surveillance data
- Assess the capability of TrEPS in evaluating alternative ITS strategies

Both TrEPS prototypes will be evaluated in a TMC environment to investigate the real-time operational functionality, estimation and prediction accuracy, computational efficiency, robustness, and applicability. This evaluation will also be used to develop benefit measures in terms of delays, safety, and environmental impacts.

The TMC evaluation of TrEPS will be performed in four stages: (i) off-line, open-loop evaluation, (ii) on-line, open-loop evaluation, (iii) off-line closed-loop evaluation, and (iv) on-line closed-loop evaluation.

6.3.1 Off-line, open-loop evaluation

This task is to evaluate the *accuracy, robustness, benefits*, and *applicability* of the prototypes.

- The accuracy of the estimations and predictions will be based on how well the TrEPS system output compares with the real data (surveillance data).
- Robustness will involve testing the quality (accuracy) against varying levels of surveillance coverage and quality, time-of-day, incident and non-incident traffic conditions, and other factors.
- Benefits will be determined by evaluating the network state with and without TrEPS-based route guidance.
- Applicability will be evaluated based on the quality of the synthetic OD generated, usefulness of the estimated and predicted data to TMC operators (use in generating VMS guidance, signal controls, speed advisory, incident management, etc.)

The prototypes will be calibrated and run offline using historical data (e.g., network traffic conditions, demographics, and ODs), archived surveillance system data, incident data, and all corresponding VMS/guidance and signal control information implemented by TMC operators.

The TrEPS prototypes will be calibrated using cleaned, off-line traffic data. The prototypes will be evaluated to identify: (i) applicability and quality of synthetic OD generated; (ii) quality of estimated and predicted information, (iii) capability and quality of guidance information, and (iv) impact of data quality and quantity on the performance of the system. The synthetic OD generated by TrEPS will be compared to the historical OD data available for the test site.

This test is called an open-loop test because the data generated by TrEPS will not be used by the TMC operator to alter network conditions. That is, the information will not be shared with drivers, and no new traffic management strategies will be implemented as a result of this data.

6.3.2 On-line, open-loop evaluation

This evaluation is to evaluate the *real-time operational capability*, *self-calibration capability*, *robustness*, and *TMC application potential* of the TrEPS prototypes. Applicability will be tested based on which of the outputs from TrEPS could be used by the TMC operators to set signal controls parameters and provide information.

The prototypes will be installed at the test site and given real-time surveillance data, VMS data, signal control, and historical data. The surveillance data and VMS data will be fed directly in real time to the TrEPS prototypes; and the prototypes will be run on-line in an open-loop fashion.

TrEPS will be run on-line, receiving surveillance data from the test bed directly. In this open-loop evaluation, TrEPS data will not be used to alter traffic conditions. The main objective of the evaluation is to test the real-time operational capability of the prototypes in terms of how well they meet the real-time operational constraints and the quality of their estimations and predictions using real-time (not so reliable) surveillance data. Other possible applications of TrEPS-generated information at the TMC will also be evaluated.

6.3.3 Off-line, Closed-loop evaluation

This evaluation will address issues related to effectiveness of guidance strategies, integrability requirements, real-time integrated operations, and deployability of the TrEPS prototypes. The real-time integrated operations potential will be evaluated based on how well the prototype systems meet real-time operations constraints and whether they are able to produce the data required by the TMC operators in time. The deployment potential will be evaluated based on the types of information produced by TrEPS and their usefulness to the TMC operators in setting VMS messages and generating real-time traffic control plans. This will be evaluated for both incident and non-incident conditions. The effectiveness of guidance will be evaluated by comparing the MOEs generated by TrEPS “with” and “without” guidance. The effectiveness of guidance will be evaluated for both incident and non-incident conditions.

Under this task, the prototypes and ground-truth simulator (e.g. Paramics, MITSIM) will be provided with historical and surveillance data and will be run off-line in a closed loop. The ground-truth simulator represents the “real-world” and interacts with the prototypes as in the real world. The guidance from the prototype systems will be used in the ground-truth simulator to provide actual guidance. The surveillance information is passed from the simulator to the prototype systems to enable them to perform estimations and predictions. The output from TrEPS and the ground-truth simulator can be compared to evaluate the quality of the estimates and predictions and the network performance.

6.3.4 On-line, Closed-loop evaluation

This evaluation is to address the real-time implementation and operation issues of TrEPS on the traffic management in the TMC. A real-time stream of surveillance data will be fed directly into TrEPS. Predictive traffic information generated by TrEPS will be passed to the TMC operators who will adjust the traffic controls accordingly. This information could be directly passed to travelers via the VMS and other traveler advisory systems available at the test site or could be used to generate control strategies or other types of information required by the TMC operator. In addition to evaluating the traffic prediction capability of TrEPS, the benefits of implementing TrEPS-based information in the test site can be investigated.

It is envisioned that this evaluation will constitute an on-line, "virtual" closed-loop system at the TMC. A "real" closed-loop can only be realized when the development of TrEPS becomes mature and the predictive traffic information is of value to the TMC operators in making decision on real time traffic control. Therefore, a comprehensive on-line, closed-loop evaluation will not be conducted until TrEPS is capable of generating useful information for the TMC operator.

MIT completed the off-line, open-loop evaluation of DynaMIT by August 2002 and UMD will complete the similar evaluation of DYNASMART-P by May 2003. The evaluation reports were posted at the DTA website.

[Due to lack of real time data at the selected site (Caltrans ATMS test bed) and limited resources, only "off-line, open-loop evaluation" was conducted using (5 days) archived data collected from the site. The on-line applications will be evaluated under Phase 2B.]

6.3.5 Using TrEPS with Other Systems

In order for TrEPS to interact and operate with other systems in the expected fashion, all of these systems must have a common "understanding" of the shared data semantics and syntax. The development and testing of the required TrEPS interface will be coordinated with the common data model (ATMS Research Analysis Database System, or ARADS) developed by FHWA and the data model descriptions developed under the Traffic Management Data Dictionary (TMDD) effort. A common TrEPS data model and database will be developed for the exchange of data among the TrEPS systems, ground-truth simulators, the TMCs, and other planning tools. The common data model and database will be developed to be compatible with ARADS capabilities. The exact syntax of the data can always be translated from one format to another as long as the semantic content of the data is understood and compatible.

A TrEPS Interface Control Document (ICD) was developed under the Phase 1.5A to address the interoperability issue. The document will be updated to streamline with the ARADS and TMDD projects and will be published so that it is readily available to users.

6.4 Phase 1.5C: Evaluate of TrEPS-P

Performance Period: 7/2000 – 1/2002

This evaluation is to assess TrEPS-P's capabilities in the application areas as stated in Section 2.1.4. Phase 1.5C will be focusing on the two high priority application areas:

- Assess the applicability of the TrEPS-P in work zone. That is, assess its capability to perform traffic impact analyses before, during, and after construction and to evaluate alternate traffic management and control strategies for work zone planning.

- Explore the benefits of using the prototypes in the traditional transportation planning process to address the dynamic traffic assignment issues.

The main tasks of the TrEPS-P evaluation will be:

- Data Requirements Analysis – to assess data needs and data availability and to synthesize data for evaluation of the specific applications (e.g., traffic impact analysis for work zone planning and dynamic traffic assignment)
- Development of TrEPS-P Calibration and Evaluation Plan for Specific Application Areas
- Development of Interface Control Document (ICD) and Common Data Base for TrEPS-P and Planning Models
- Execution of the TrEPS-P Calibration and Evaluation Plan
- Development of Initial Training Package with Case Studies
- Final Report – to provide evaluation findings and recommendations

Phase 1.5C was completed by 8/02 and the final reports were delivered in February 2003. DYNASMART-P was recommended by ORNL for field evaluation in Knoxville, TN in Phase 1.5C.

[Note: Two reasons caused the delay of the Phase 1.5C project: (1) delay of the work zone data collection activities in Knoxville, TN and (2) the UTX's DTA team relocated from UTX to UMD in August 2002.)

6.4.1 TrEPS-P Evaluation Framework and Evaluation Strategy

Figure 9 presents a general TrEPS-P evaluation framework. For a candidate TrEPS-P prototype, the framework starts with an experimental design. The objective of the design is to formulate a systematic approach to conducting a large number of evaluations of interest. More specifically, the experimental design is to determine a small set of scenarios that can be generated to cover most of the evaluation requirements, based on the selected set of key TrEPS-P variables. These scenarios will be generated using the baseline data from the evaluation site data set. The evaluations are to be conducted through examinations of TrEPS-P outputs and data from evaluation site data set, including various measures of effectiveness (MOEs) and comparisons of outputs from different scenarios.

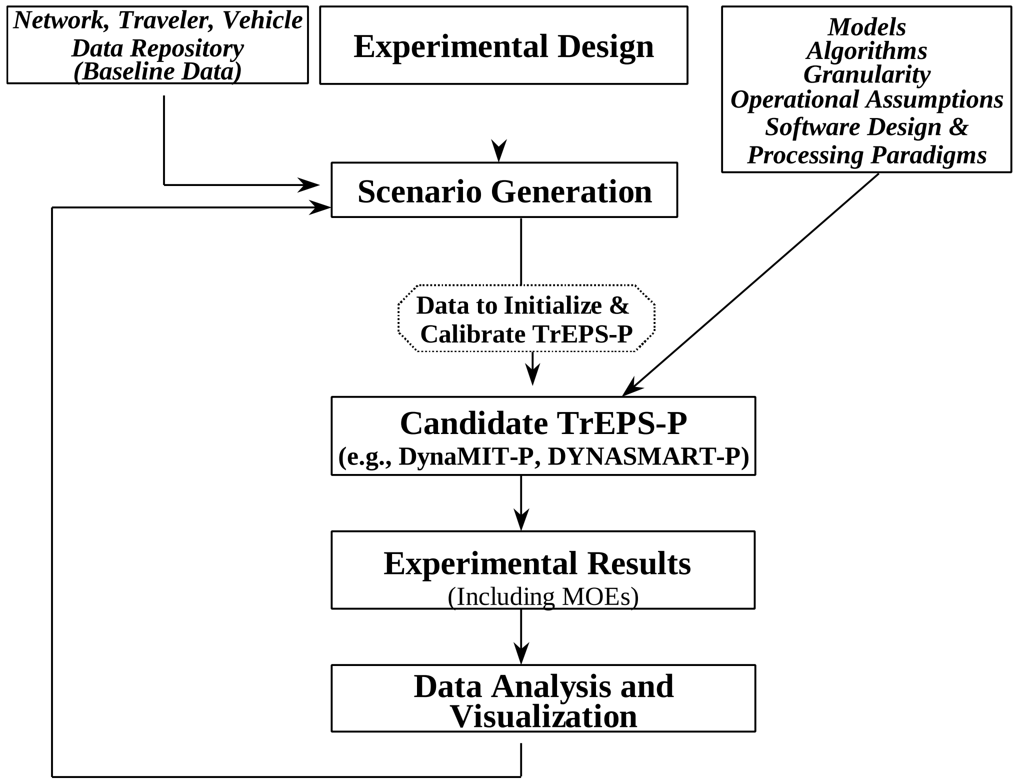

Figure 9: MPO Evaluation Framework

General evaluation strategy is as follows:

Step 1: For particular application the benefits to be evaluated will be listed.

Step 2: Scenarios will be generated for each of the benefits to be evaluated.

Step 3: The site data will be examined to determine the availability of data for generating the scenarios. If data elements are available then the data will be used to set up the scenarios.

Step 4: If the data required for generating a scenario is not available at the site then the data could be synthesized based on the site data or obtained from other agency if possible. The data thus synthesized or obtained from other agency will be called synthesized data.

Step 5: Evaluation will be performed using the data obtained from site or synthesized.

Step 6: A detailed evaluation plan will be developed at the beginning of the evaluation task. The plan will include as a minimum descriptions of: application being evaluated, expected benefits, scenarios for evaluating each of the benefits, data required/available/synthesized for each of the scenarios, and expected results for each of the scenarios.

In Phase 1.5C, partnerships will be established with MPOs so that the systems can be deployed in an MPO environment and its planning capabilities and functionality can be evaluated and refined.

6.5 Phase 2: Enhancements, Initial Deployments, and Technical Support

Phase 2 consists of three parallel phases, 2A, 2B, and 2C. The objective of Phase 2A is to maintain and enhance the prototypes in support of the FHWA R&D studies, TrEPS and TrEPS-P testers, and initial deployments and applications. In Phase 2B, FHWA will seek partnerships with state and local agencies to perform initial deployments to address needs of each specific site and to further refine the TrEPS prototypes for more applications. In Phase 2C, FHWA will rollout the TrEPS-P prototype(s) and form partnerships to perform initial deployments to assess software capabilities in addressing modeling needs in areas of national significance, such as emergency transportation operations, evacuation planning, critical infrastructure analyses, etc. In Phase 2C, FHWA will also conduct demonstration, training workshops, beta testing, and outreach activities. In addition, the TrEPS-P software and documents will be packaged for public release.

6.5.1 Phase 2A:TrEPS/-P Maintenance and Enhancements

Performance Period: 1/2002 – 12/2003

Phase 2A is mainly to support R&D efforts to be taken under Phases 2B and 2C. This phase is to maintain and enhance the TrEPS and TrEPS-P software and documents and to provide technical support to the FHWA R&D studies and initial users and testers prior to public release. Any enhancements such as improving computational efficiency and modeling capabilities, ease of use, problem fixes, etc. to facilitate the use of the prototypes will be performed under this phase. The following are the potential enhancement areas and the estimated costs:

- Integrate TrEPS prototypes with microscopic traffic simulation models such as MITSIM, Paramics, and CORSIM to evaluate different ATIS and ATMS strategies in the ITS context. Initial focus will be on the refinement of the common scenario database specifications and the Interface Control Document for developed by ORNL under Phase 1.5B. (For example, TrEPS-P will produce “flow” data for CORSIM to simulate for detailed operational analyses.)
- Enhance the input data editor for TrEPS/TrEPS-P. The network input editor should be able to “import” input data from traditional planning models.
- Integrate the TrEPS-P prototype(s) with TSIS Shell.
- Develop a license/CORBA-free Linux based DynaMIT/-P to help rollout DynaMIT-P
- Develop a Windows based DynaMIT/-P to help rollout DynaMIT/-P.
- Enhance the TrEPS prototype(s) based on test findings or new requirements.
- Enhance the TrEPS-P prototype(s) based on test findings or new requirements.

- Emergency transportation operations
- Evacuation Planning
- Critical transportation infrastructure analyses
- Weather issues

(Note: The scope of the work may be changed based on the availability of funds, national R&D needs, and outcomes of the field evaluation of TrEPS and TrEPS-P from Phases 1.5B and 1.5C.)

6.5.2 Phase 2B:Partnership for Initial Deployments of TrEPS

Performance Period: 1/2002 – 12/2005

Phase 2B is to seek partnerships with state and local agencies to perform initial deployments to address needs of each specific site and application and to further refine the TrEPS prototypes for more applications. The following tasks will be performed:

- Form a partnership with Houston TranStar to integrate DYNASMART-X with Claire and RHODES for real time traffic management along the I-10 (West) corridor and to evaluate the system for online application.
- Form a partnership with LA DOT to integrate DynaMIT with Claire and the LA's incident detection system for real time traffic management on arterials and to evaluate DynaMIT for online application.
- Form a partnership with VDOT, the University of Virginia, and MIT to evaluate DynaMIT on Hampton Roads, VA. Stage 1: Perform offline evaluation of DynaMIT with archived data and explore the possibility of on-line application.
- Form a partnership with Maryland State Highway Administration and the University of Maryland to integrate DYNASMART-X at the CHART system.
- Develop preliminary outreaching and marketing packages in using TrEPS.
- Form partnerships with other state and local DOTs to deploy TrEPS.

6.5.3 Phase 2C: Partnership for Initial TrEPS-P Deployments and Rollout

Performance Period: (1/2002 – 12/2003)

Phase 2C is to identify and schedule outreach activities to showcase and roll out the TrEPS-P prototypes. FHWA will conduct demonstration, training workshops, beta testing, and outreach activities prior to public release of the software. In this phase, we also seek partnerships to perform initial deployments to assess software capabilities in addressing modeling needs in areas of our interest, such as emergency transportation operations, evacuation planning, critical infrastructure analyses, traditional planning analyses, etc.

It is planned to release the TrEPS-P package through the FHWA software distribution centers at McTrans and PCTrans.

To accomplish the objectives, the following tasks will be performed:

- Demonstrate TrEPS-P (TRB, ITSA, ITE, etc.)
- Award the Phase 2C work to UTX/UMD to roll out DYNASMART-P through the interagency agreement with ORNL.
- Conduct initial TrEPS-P training workshops.
- Conduct beta testing and enhance TrEPS-P.
- Conduct an independent test and evaluation of DTA-related software packages and perform the pre-release test. In FY03, McTrans will conduct beta test and pre-release test of DYNASMART-P and DYNASMART-P Network Editor.
- Develop release packages of TrEPS-P.
- Form partnerships with MPOs and planning agencies to perform initial field deployments. The following will be the candidate sites for partnerships:
    - Southern California Association of Governments (SCAG) - to apply DYNASMART-P methodology for operational planning in a selected site in LA.
    - Minnesota State DOT - to develop and evaluate emergency evacuation strategies with DYNASMART-P.
    - Texas State DOT - to conduct evacuation planning analysis in the El Paso area using DYNASMART-P.
    - Others (TBD)
- Develop outreach materials, including workshops and NHI TrEPS-P training modules

6.6 Phase 3: TrEPS and TrEPS-P Maintenance, Enhancement, and Rollout

Phase 3 is to continue to maintain and enhance the TrEPS and TrEPS-P prototypes in support of FHWA R&D activities, advanced traffic modeling analyses, emergency transportation operations, security analyses, field deployments and TrEPS and TrEPS-P users. In addition, this phase is also to foster partnerships for long-term research, development, evaluation, and deployment of TrEPS and TrEPS-P. Only Phases 3A and 3B will be included in Phase 3. Phase 3A is a continuation of Phase 2A to maintain and enhance TrEPS and TrEPS-P in support of FHWA R&D needs, field deployments, TrEPS and TrEPS-P users, and any emerging modeling needs. In addition, TrEPS and TrEPS-P will be enhanced based on lessons learned from the initial deployments in Phase 2B. Phase 3B is also to rollout the TrEPS packages for more field deployments. Since TrEPS and TrEPS-P share the same core code, any enhancements to be made to TrEPS will be included in TrEPS-P accordingly.

6.6.1 Phase 3A: Maintenance, Enhancements and Technical support

Performance Period: 1/2004 – 12/2008 or beyond

Phase 3A is a continuation of Phase 2A to maintain and enhance TrEPS and TrEPS-P in support of FHWA R&D needs, field deployments, TrEPS and TrEPS-P users, and any emerging modeling needs. In addition, TrEPS and TrEPS-P will be enhanced based on lessons learned from the initial deployments in Phase 2B. This will be a long-term research and development phase to enhance and maintain the software packages in support of any on going and emerging modeling needs. The following enhancements are potential areas of interest:

- Add new requirements for emergency transportation operations, such as reversing freeway lanes for evacuation in ONE direction, critical transportation infrastructure analyses, critical employment centers and buildings analyses, and any emerging modeling needs to address issues in the context of emergency transportation operations and security.
- Add new requirements for weather analyses and investigate effects of the weather on the transportation network and benefits of using weather-responsive traffic control strategies in bad weather (e.g., re-timing signal timing sets in bad weather along the arterial corridor.)
- Model new ITS surveillance and detection technologies, such as cellular phones, vehicle to roadside communications with beacons, wide area surveillance and detection (cameras), AVI, EZPASS, new technologies to track down vehicles (i.e., loop detectors with vehicles' signatures) etc. to improve traffic estimation and prediction capabilities.
- Improve existing algorithms for computational efficiency to meet real time needs.
- Improve the TrEPS and TrEPS-P prototypes to model emerging technologies in ATMS and ATIS.

- Provide technical support to DYNASMART-P Users.
- Provide technical support to DynaMIT-P Users.
- Conduct an independent test and evaluation of DTA-related software packages and perform the pre-release test. We anticipate that any new or modified software packages should be independently tested at McTrans.
- Support FHWA R&D studies such as integrating the TrEPS prototypes with microscopic traffic simulation models to assess impacts of different ATMS and ATIS strategies.
- Modularize the “driver behavior” component to experiment different driver’s behavior algorithms via the external interface.
- Calibrate TrEPS with (archived) field data for more applications such as evaluation of existing traffic control strategies, drivers’ responses to traffic control strategies, weather effects on network performance, effects of ATIS on network performance, etc. Exploration of speed-density relations in different scenarios (e.g., weather) will be our high priority work.
- Calibrate TrEPS-P with field data for more traffic operations planning applications such as network-wide ITS and non-ITS alternative analyses, including traffic impact analyses for work zones, incident management, HOV/HOT lane(s) analyses, ramp metering, evacuation planning, etc.
- Form partnerships with other state and local agencies to perform more field deployments of TrEPS-P.

6.6.2 Phase 3B: TrEPS Rollout

Performance Period: 1/2006 – 12/2008 or beyond.

Phase 3B is to rollout the TrEPS packages for more field deployments. Partnerships will be formed to promote TrEPS for on-line traffic management applications. Training workshops for potential users and marketing materials will also be developed. The Primary tasks of Phase 3B will be to:

- Form a user group of TrEPS users for exchanging experiences and providing feedback for further R&D. The candidate agencies will be: ATSAC of LA DOT, Houston TranStar, Hampton Roads TMC, VA, VDOT, NYSDOT, MN DOT, FLD, MDSHA, the CHART system of MD SHA, etc.
- For partnerships with other state and local agencies to perform more field deployments of TrEPS.

- Provide training workshops for potential TrEPS users.
- Develop outreach and marketing materials to promote TrEPS.

(Note: The scope of the work may change based on the availability of research funds.)

7 BENEFIT POTENTIAL

The ultimate benefits of TrEPS and TrEPS-P will help decrease traffic congestion and travel delays, which should translate into improved mobility and productivity and decreased pollution from vehicle emissions. These systems can also be used to improve safety (e.g., in work zone design and management). In addition, in a multi-jurisdictional environment, TrEPS can be used to help coordinate the activities of various ITS services and technologies, such as commercial vehicle operations (CVO) and emergency management systems (EMS), facilitating improved efficiency of these systems.

The following illustration of the benefits was derived from a presentation (a hypothetical case study) prepared by the UTX development team (UTX 1999). It shows the potential benefits, in terms of average system travel time, derived from (1) TrEPS-generated diversion and (2) combined diversion and signal coordination.

Network: Fort Worth I-35W corridor.
Normal condition: The corridor is highly congested during morning peak hours with average travel time being 25 minutes to cross the corridor.
Scenario description: Demonstrates the benefits of TrEPS under incident conditions. An incident occurs on a freeway link that lasts for 20 minutes, reducing its capacity by 75%, increasing the average travel time to 29.4 minutes.
Benefit: When the TrEPS-generated diversion advisory was displayed on VMS for the users of the facility, the average travel time was reduced to 24.7 minutes (a 16% reduction on average). When signals along the arterials are optimized along with centralized system optimal routing strategies, the system-wide average travel time drops to as low as 14.0 minutes (52%). In reality, the benefits derived from implementing proactive guidance and control plans based on TrEPS predictive information will be between 10% and 52%.

Illustration of Potential Benefits of TrEPS

These types of experiments validate the expected benefits from TrEPS-based systems (i.e., systems that generate proactive traffic management and information strategies) as detailed in *National ITS Deployment Strategy* (ITS America 1999). The example also indicates that benefits derived by coordinated control and guidance can be much greater than benefits derived through single services alone.

8 SUMMARY

This paper provides a Roadmap for the FHWA's DTA research project for the research, development, evaluation, and deployment of a real-time Traffic Estimation and Prediction System (TrEPS) and an offline version of the system for planning (TrEPS-P).

The need for TrEPS capabilities is clearly stated in the National ITS Architecture report, and TrEPS forms the basic support function of many ITS marketing package deployments. Without TrEPS-based deployment, the full potential of the marketing packages identified in the National ITS Architecture report will not be realized. Furthermore, the potential benefits of TrEPS are in line with the FHWA's strategic goals.

This paper identified the major applications of TrEPS as well as TrEPS stakeholders. The DTA Project research has produced two TrEPS prototypes: MIT's DynaMIT and UTX's DYNSMART-X. These prototypes are based on the same underlying design framework, but they vary in terms of representation, assumptions, operation scenario, and implementation.

Initial laboratory experiments show that the benefits derived from TrEPS-enabled ITS services range from approximately 10% to 50%. One of the objectives of the Phase 1.5A is to document the benefits derived from TrEPS during the laboratory and TMC evaluation. Benefits will be recorded during both open-loop and closed-loop evaluations.

The DTA research project also produced two TrEPS-P prototypes: MIT's DynaMIT-P and UTX's DYNSMART-P. Both systems are based on their real-time counterparts (DynaMIT and DYNASMART-X) with expanded data output and statistical analysis capabilities. These systems were delivered to ORNL in February 2000 under the Phase 1.5A.

Following the laboratory evaluation phase (1.5A), the TrEPS and TrEPS-P prototypes will be tested in the field. TrEPS will be evaluated in the TMC under both simulated and real-world, real-time conditions (Phase 1.5B); while TrEPS-P will be deployed in MPOs and used for short-term planning applications (Phase 1.5C).

Following field evaluations, the systems will be refined and expanded under Phases 2 and 3, and additional partnerships with TMCs and MPOs will be established. In these phases, market packages and training materials will also be developed to promote the effective use of these systems.

9 REFERENCES

TrEPS Summary Brochure

DynaMIT Summary Brochure

DynaMIT Summary Brochure

DYNASMART-X Brochure

DYNASMART-P Brochure

DynaMIT Evaluation Final Report, Vol. 1, MIT, February 2003

DynaMIT Evaluation Final Report, Vol. 2, MIT, February 2003

DYNASMART-P Evaluation Final Report, Vol. 1, UMD, February 2003

DYNASMART-P Evaluation Final Report, Vol. 2, UMD, February 2003

DynaMIT User's Guide, Linux Version 2.0, MIT/Volpe, February 2003

DynaMIT-P User's Guide, Linux Version 2.0, MIT/Volpe, February 2003

DynaMIT User's Guide, Unix Version 0.99, MIT, September 2002

DynaMIT-P User's Guide, Unix Version 0.99, MIT, September 2002

DynaMIT and DynaMIT-P, Programmer's Guide, Part 1, MIT, March 2003

DynaMIT and DynaMIT-P, Programmer's Guide, Part 2, MIT, March 2003

DYNASMART-P Programmer's Guide, Version 0.930 (incomplete version), UMD, February 2003

DYNASMART-X User's Guide, Interim Report, UMD, February 2003

DYNASMART-X Programmer's Manual, Interim Report, UMD, February 2003

TMC Evaluation for a Real-Time DTA System Prototype: Phase 1.5B – The Irvine Testbed Interim Report, UMD, February 2003

Calibration and Validation of DYNASMART-P for Operational Planning: Application to Knoxville, (PowerPoint slides) Presented by Hani S. Mahmassani, Maryland Transportation Initiative, University of Maryland, December 5, 2002.

DYNASMART-P User's Guide, Version 0.930.2, UMD, October 2002

DYNASMART-P Training Workshop, October 7-8, 2002

TrEPS & TrEPS-P Database Version 0.91, Office of Operations RD&T, FHWA, Prepared by ITS Group, Center for Transportation Analysis, ORNL, May 3, 2001

TrEPS & TrEPS-P Interface Control Document, Version 0.9, Prepared for Office of Operations RD&T, FHWA, Prepared by ITS Group, Center for Transportation Analysis, ORNL, March 31, 2001

DTA Research Group, The University of Texas at Austin, "Benefits of DTA Predictive Information," (presentation), 1999

"FHWA National Strategy Plan Summary," U.S.DOT, FHWA, 1998

ITS America. T*he National Architecture for ITS: A Framework for Integrated Transportation into the 21st Century, 1999*

ITS America. "National ITS Deployment Strategy: Actions for achieving national and community transportation objectives," Circulation Draft, March 1999

Lee, R, Southworth, F., Summers, M., "Ideas for Incorporating Dynamic Traffic Assignment in the ITS Deployment Analysis System," Presented at the 1999 TRB Annual Meeting, 1999.

Mahmassani, H., Chiu, Y-C, Hawas, Y, Abdelghany, K., Abdelfatah, A, and Valdes, D. *DYNASMART-X: Real-Time Dynamic Traffic Assignment System, Volume IV: Off-line Testing*, Report FHWA #ST067-85, 1998

Summers, M., and Crutchfield, J. "Draft TrEPS Interface Version 0.1." Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1999

Oak Ridge National Laboratory, Independent Laboratory Evaluation of Dynamic Traffic Assignment Systems (Version 1.2), April 25, 1999

Oak Ridge National Laboratory, DTA Prototype Inspection Report: DYNASMART-X Coding Evaluation, April 25 1999

Oak Ridge National Laboratory, DTA Independent Laboratory Evaluation of DynaMIT, July 1999

Oak Ridge National Laboratory, Development of TrEPS-P: Phase 1.5C – MPO Evaluation Plan, March 27 2000

Oak Ridge National Laboratory, Development of TrEPS: Phase 1.5B – TMC Evaluation Plan, April 5, 2000