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Authors

Khattak, Asad
Kanafani, Adib

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Asad Khattak
Adib Kanafani

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PLANiTS: A FUNCTIONAL DESCRIPTION

Asad Khattak

Adib Kanafani

109 McLaughlin Hall
Berkeley, California 94720

Phone (510) 642-3585
Fax (510) 643-5456

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ABSTRACT

This paper presents a functional description of PLANiTS (Planning and Analysis Integration for Intelligent Transportation Systems). Based on our experience with a simple prototype, we describe the functions that are included in PLANiTS. Specifically, transportation improvement projects are represented as planning vectors. The vector allows users to examine the impacts of transportation actions in terms of performance measures in a certain environment. Users must specify the actions, performance measures and the environment each in terms of spatial, temporal and user dimensions. Then, they can analyze the planning vector with models, case-based reasoning and expert systems. During the process of planning vector specification and analysis, users at different locations can communicate by sending and receiving messages and sharing the planning vector. Users can examine the results in a way that allows clearer tradeoffs among alternative actions. Overall, PLANiTS facilitates a planning process that iteratively combines analysis and deliberation. In the paper, we suggest functions that can be included in future versions of PLANiTS.

Key Words: Intelligent Transportation Systems, Transportation Planning, Knowledge-Based Systems, Groupware, Modeling.

EXECUTIVE SUMMARY

The objective of this paper is to present a functional view of a planning methodology called PLANiTS (Planning and Analysis Integration for Intelligent Transportation Systems). The methodology consists of a process-based computer system that supports a series of mutually interdependent steps which progress toward developing and programming transportation improvement projects. PLANiTS can translate problems and goals to performance measures, examine possible competing and complementary actions that can address the problems, systematically evaluate the impacts of actions by using appropriate knowledge-based and model-based tools, and support human communication and interaction between planning group members. The PLANiTS methodology is non-incremental in the sense that it integrates both existing knowledge regarding transportation, and analysis using models with deliberation and resolution seeking. This methodology will likely expedite the implementation of intelligent technologies by systematically examining how they might fit in with more conventional transportation improvement actions.

Users include local, regional, and state officials involved in transportation planning as well as interested citizens and special interest groups. They can operate PLANiTS individually or in groups. The processes individuals may use include diagnosis of problems, exploration of relevant policies, search and specification of transportation improvement actions, matching of selected actions with similar actions implemented elsewhere, and evaluation of actions using models and data. In a group setting, the planning process can be collaborative or antagonistic. Collaborative teams are likely to rely on much of the same processes as the ones available to individual users; in addition, the team might also brainstorm over possible actions and performance measures, debate and scrutinize issues, critique and refute propositions, warn and advise each other against certain options or outcomes, work on answering questions, vote over controversial issues and rank criteria. At various stages in the planning process, individuals and groups can become antagonistic, especially when they cannot agree on certain aspects of a project. In such situations,

PLANiTS allows participants to dispute issues and results, bargain and haggle over aspects of projects, compromise and settle matters and sometimes conceal information from the opponents to gain a strategic advantage. PLANiTS will address important issues associated with the political process and improve the quality of debate and working of politics in planning. However, it will not eliminate politics--we realize that some aspects of the planning process will always remain beyond the scope of computer support.

An important feature of PLANiTS is that it allows users to iterate while designing their own strategy for project development. PLANiTS allows them to check for violations of requirements at project location, ensure that the project addresses certain goals and satisfies, refine and develop actions and evaluate the impacts of actions and during the whole process allows participants to communicate and deliberate over critical issues. Users can seek PLANiTS advice on issues throughout the planning process. This advice comes as actions and performance measures to be considered in a certain environment, models and data to be used, etc. The advice will be based on information about the context supplied by the user and on theoretically and empirically valid rules.

Full development of PLANiTS is an ambitious undertaking. In fact, some of the tools needed for its development, e.g., case-based reasoning, are themselves in early stages of development. In this paper, we provide a description of a simple PLANiTS prototype to demonstrate the key functions. The prototype must include a planning vector that allows users to input and edit transportation actions, performance measures and environmental descriptors. Users can specify each of these elements in detail and analyze the planning vector with models, case-based reasoning and expert systems. During the process of planning vector specification and analysis, people at different locations can communicate by sending and receiving messages and sharing the planning vector. More details about functional developments are provided in the paper.

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1. BACKGROUND

Urban transportation problems persist and are increasing in their complexity and scope. Traffic congestion, pollution, and safety problems are now a part of daily life. While these problems may be acceptable at certain levels, the current degree seems high. Lawmakers have approved legislation such as ISTEA (Intermodal Surface Transportation Efficiency Act) and the Clean Air Act to curtail the adverse impacts of travel and fund projects that address broader policy goals. New transportation technologies offer solutions to these problems, however, inappropriate technology implementation can sometimes lead to the worsening of the problems. Therefore, a planning methodology that seeks to address large scale transportation problems needs to be open and policy relevant.

Although technologies offer opportunities, there is a gap between their development, assessment of appropriateness in a specific context and proper implementation. Importantly, in transportation planning, there is a complex and often muddled political process that precedes the implementation of transportation projects, and this process is also crucial to the implementation of intelligent transportation technologies in the future. It is likely that intelligent transportation technologies will not necessarily dominate the planning process, rather they may act as catalysts for change. There seems to be a fair amount of skepticism within the transportation planning community regarding the role of new transportation technologies, i.e., some are not convinced regarding the benefits of new technologies. Therefore, a new planning methodology should allow participants to examine tradeoffs and evaluate impacts/benefits and sharpen insights in an interactive environment.

The implementation of new transportation technologies is complicated because they must be eased in to the existing transportation system. This encourages incrementalism rather than innovative new approaches. It promotes the status quo, possibly hampering new and creative solutions. However, to address problems comprehensively, a planning methodology must enhance creativity in exploring innovative solutions.

A new planning methodology also needs to integrate the structured methods, i.e., transportation planning and operational models, with semi-structured analysis techniques such as knowledge-based systems and unstructured electronic support. A methodology called PLANiTS, which stands for Planning and Analysis Integration for Intelligent Transportation Systems, was proposed for this purpose (a detailed description of PLANiTS appears in Kanafani, Khattak, Crotty and Dahlgren 1993; Kanafani, Khattak and Dahlgren 1994 and Vlahos, Khattak, Kanafani, and Manheim 1994). PLANiTS is a comprehensive tool designed to meet the needs of emerging planning processes. While structured analysis and modeling have been widely used in transportation planning, their integration in an open and deliberative planning environment supported through electronic brainstorming and computer dialogue is new with PLANiTS. Moreover, it incorporates synthesized transportation knowledge for diagnosis, evaluation and examination of tradeoffs. Also, new with PLANiTS are expanded opportunities for considering alternative assumptions, goals, and strategies for addressing transportation problems. PLANiTS is designed to be accessed and used by all agencies and people involved in transportation planning.

The basic functions provided by PLANiTS are presentation of information to participants, analysis of transportation improvement actions, communication between individuals, and judgement on planning issues. To summarize, PLANiTS:

- Is "human" process-based and consists of a series of mutually interdependent iterative steps that progress toward developing a project.
- Is open-ended (e.g., technical issues are open to debate and critique) and accounts for single human working alone and in collaborative or antagonistic groups.
- Integrates state-of-the-art models in a unified framework along with tools for developing new models.
- Uses previously accumulated knowledge, appropriately synthesized, to address the policy, analysis and programming issues at hand.

- Uses tools that support group processes involved in making analysis and programming decisions.
- Provides intelligent advice (when requested) throughout the planning process.

1.1 A Retrospective View: Expansion of PLANiTS Scope

We started the PLANiTS project with a view to develop a set of transportation planning models for intelligent transportation systems. The models included new theoretical formulations, computer illustrations and in some cases, empirical validation from field operational tests. The goal was to produce a revised UTPS (Urban Transportation Planning System) type model structure, fit for use with intelligent transportation systems. However, we realized that the transportation planning process was political and deliberative. Further, that the transportation planning models were not completely value-neutral and may incorporate developer biases. Analysis conducted with state-of-the-art models can be challenged on various grounds, both technical and nontechnical. Therefore, it is important that groups involved in planning agree on model assumptions before conducting analysis. The support could come as a computer-based dialog about the models and their results. We also found that computer-based support systems were being developed for complex deliberative and negotiating processes (Vlahos, Khattak, Manheim and Kanafani 1994; Vlahos, Manheim and Xie 1995). These systems have been typically applied to private sector problems, but they are ripe for application to transportation planning. The systems could result in enhanced human creativity, greater awareness of problems and issues and resolution of conflict. Providing tools that support deliberation and judgement, providing a logic that integrates existing state-of-the-art models, providing access to generic model building methods to address new problems as they arise and presentation of tradeoffs are considered necessary for PLANiTS. Overall, PLANiTS has evolved considerably since its inception and is still being refined and developed.

1.2 A Futuristic View of PLANiTS

PLANiTS supported processes include diagnosis of problems, exploration of relevant policies and their implications in terms of constraints, violations and conformity requirements, selection of appropriate performance measures, search and specification of transportation improvement actions, and evaluation of actions by running models. The participants can also learn about current policies, model structures and their inputs and outputs, etc. Furthermore, the participants can examine data by querying the data base, calculating descriptive statistics, sorting data and estimating new models. The participants are presented with the results in a format that helps interpretation. Sometimes participants may be required to measure variables that are needed, but not available in PLANiTS.

In a group setting, the planning process can be collaborative or antagonistic. Collaborative teams are likely to rely on much of the individual processes and in addition teams might brainstorm over possible actions and performance measures, debate and scrutinize issues, critique and refute propositions, warn and advise each other against certain options or outcomes, suggest alternative ways of addressing the problem, work on answering questions, reason out things as they go through the process, give opposing views, report to bosses about various aspects of a project, vote over controversial issues, rank and weight performance criteria, transmit messages, chat, disclose information and contest issues.

At various stages in the planning process, individuals and groups can become antagonistic, especially when they cannot agree on certain aspects of a project. In such situations, participants may be more likely to dispute issues model results, bargain and haggle over aspects of projects, compromise and settle matters and sometimes conceal information from the opponents to gain a strategic advantage. In some cases, arbitration may be needed to settle issues.

PLANiTS attempts to support and enhance these processes. Specifically, PLANiTS helps users propose, design and document transportation improvement projects, seek funding and negotiate with relevant groups. Participants can operate PLANiTS individually or in groups.

Moreover, PLANiTS also provides processes that are currently not used in planning, e.g., matching proposed actions with similar actions implemented elsewhere to obtain insights.

PLANiTS will address important issues associated with the political process and improve the quality of debate and working of politics in planning. However, it will not eliminate politics-we realize that some aspects of the planning process will always remain beyond the scope of computer support.

1.3 PLANiTS Components

The PLANiTS architecture, developed during the earlier stages of the study, is based on two fundamental processes: analysis and group interactions. Analysis includes not only using models but also the use of intelligence and reasoning. Group interactions include deliberative planning, resolution seeking and project programming. These are supported through various bases described in Kanafani et al. (1994) and discussed briefly below (figure 1):

- The Policy and Goals Base contains mandates objectives and constraints communicated in terms of appropriate policy factors to be satisfied and measures of performance. It also contains a set of rules that link policies to performance measures and actions.
- The Strategy and Action Base contains a catalogue of possible actions and rules based on associated action relationships.
- The Data and Knowledge Base contains and provides access to data bases and has knowledge in terms of theoretical and empirically established relationships between transportation objects. Specifically, case-based reasoning and rule-based reasoning are both used to analyze actions.
- The Methods and Tools Base contains transportation models and generic methods of analysis, and utilities and tools, e.g., for network analysis. The base is structured such that intelligence about applying models and rules for data transformation are available to

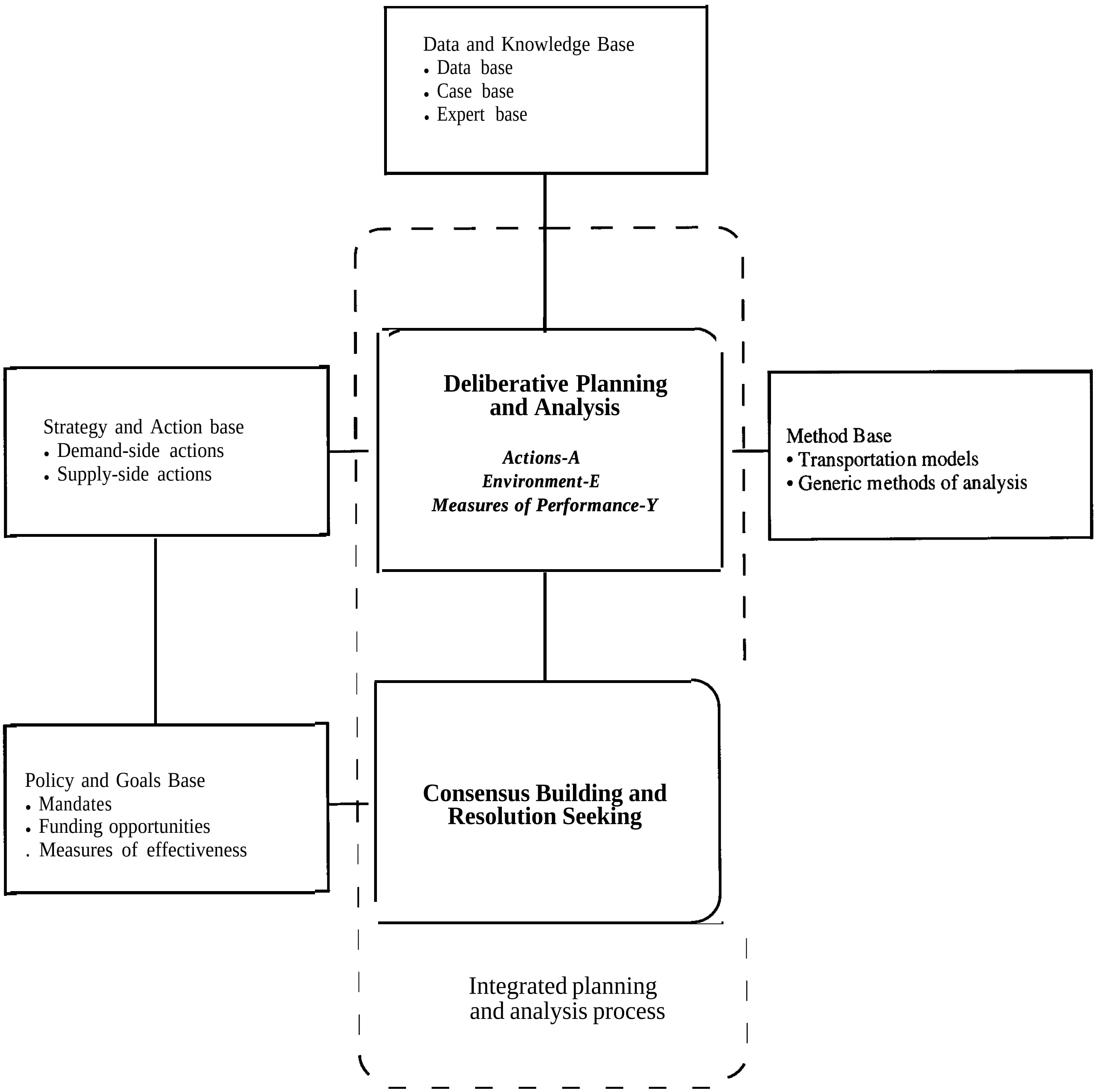

Figure 1. PLANiTS components. (Source: Kanafani, Khattak and Dahlgren 1994)

guide users.

These bases are handled by various agents. The process of group interactions is supported through a set of building block functions handled by the deliberation tool. In the prototype, we must develop each component of the architecture while allowing deliberation and resolution seeking to occur at all stages. We have integrated the representation of components in a unified framework.

The glue that binds PLANiTS components and allows deliberative planning and analysis processes to occur is the Planning Vector, **PV,** which contains three sub-vectors:

- Action Vector, A = $\{\mathbf{a_i}\}$, which contains the proposed set of actions that are the subject of the planning process. The action vector is conceptually part of the strategy and action base.
- Criteria Vector, Y = $\{\mathbf{y_i}\}$, which contains the measures of performance representing the goals for which the actions are proposed, and the criteria on the basis of which they are evaluated. The criteria vector is conceptually in the policy and goals base.
- Environment Vector, E = $\{\mathbf{e_i}\}$, which contains the descriptors of the context that are relevant to the subject actions. The environment vector is conceptually part of the data base.

We have, **PV = [A, Y, E]**

The planning vector can be constructed individually or in groups. Group interactions will likely modify and re-modify the planning vector, that is, the planning vector is constantly changing in response to participants conducting analysis, inspecting results, deliberating, communicating and passing judgements. The knowledge and the methods bases can be used to analyze the elements of the planning vector and the results used to inform the decision making process involved in programming projects. The starting point could be the action vector A, if the project is generated exogenously or it could be the criteria vector Y if a set of goals is used to start the search for appropriate actions.

2. PLANiTS PROTOTYPE

A summary of our efforts to operationalize PLANiTS into a prototype is provided. We assert that full development of PLANiTS is an ambitious undertaking requiring many more years. Some of the tools needed for PLANiTS development, e.g., case-based reasoning, are themselves under development. The prototype has a shell of the overall PLANiTS structure that can be demonstrated in a desktop computer environment (Cayford, Khattak, Kanafani 1995). Here we describe the development and refinement of functional specification, based on experience gained from prototype development.

The development of PLANiTS prototype was subject to many iterations, review and change. Much energy was devoted to making the prototype flexible while avoiding complexity and maintaining efficiency within reasonable cost. The design process was largely evolutionary. Development of a PLANiTS prototype simply could not be accomplished by following one of the text book approaches (Sommerville 1992). Instead, we followed a hybrid approach where sometimes we iteratively developed requirements, specification, software design and implementation, while at other times we established system requirements through the prototype itself. At still other times we assembled available components rather than create new ones.

During the requirements stage, system services and, constraints and goals are established in consultation with the users. PLANiTS services should include the provision of analysis and iterative human processes. Users include diverse groups consisting of state officials, transportation planning organizations and local/county officials as well as interested citizens. Designing a system to satisfy the concerns of such diverse groups remains challenging.

The PLANiTS prototype is written in C++ and currently runs on a Macintosh system. This platform was chosen because it is convenient to use, easy to produce a graphical interface, has reasonably good multi-tasking and networking capabilities and provides good scalability (speed and memory). However, most available transportation software currently operates on the PC--a potential problem for integrating transportation modeling software.

In the PLANiTS prototype users can input and edit transportation actions, performance measures and environmental descriptors. Users specify each of these elements in detail and subsequently analyze the planning vector using models, case-based reasoning and expert systems. During the process of planning vector specification and analysis, people at different locations can communicate by sending and receiving messages and sharing the planning vector. Below, we describe how users may utilize various functions available in PLANiTS.

2.1 A Description of the PLANiTS Process

Participants or a single user can begin a PLANiTS session by either connecting to a currently running planning session through a network or commencing a new session (see PLANiTS user's guide by Cayford, Khattak, and Kanafani 1995). All computer communications occur in real-time, so at least two user groups at different locations can interact and work jointly on one planning vector.

Participants can perform the following processes in PLANiTS.

- *Selectproject type.* Projects typically belong to certain categories: for example, they can be roadway, transit, bicycle/pedestrian, intermodal/freight. Participants make decisions on what specific actions and complementary actions are relevant.
- *Select goals to be achieved.* The goals and policies translate to more specific performance measures that must be calculated and actions that might or must be implemented.
- *Select the environment.* This requires that the project boundaries be identified.
- *Choose appropriate methods for evaluation.* This means the selection of models and data,

and the selection of appropriate knowledge-based tools for evaluation.

· *Interact with otherparticipants.* There are debates, review and re-review on every and all aspects of the planning process.

Let us assume that participants decide to develop and analyze a new planning vector. Participants begin working on the planning vector list by adding and removing elements after creating and naming it. The vector must have at least one of each: action, performance measure and environmental descriptors. Participants can fill in the planning vector by choosing elements from lists.

A novel way of adding elements to the planning vector is by defining the context. The context is defined by participant's agency (Congestion Management Agency, city, county, transit agency, Regional Transportation Planning Organization, citizens' group) and the policy of interest. This and additional information are used to provide intelligent advice in constructing the planning vector. For example, PLANiTS can suggest performance measures if the users indicate their interest in ensuring that certain policy factors are addressed. Specifically, participants can choose among the policies of interest (ISTEA, Clean Air Act, Americans with Disability Act, Proposition 111). For ISTEA, a list of the "fifteen factors" appears. If participants check "congestion relief' from the checklist, then PLANiTS suggests that delay be included in the planning vector. Participants can accept or override this suggestion. Of course, refinements are subject to debate, review and re-review. Similarly, if users show interest in Intelligent Vehicle Highway Systems or IVHS (ISTEA supported actions), then ATMIS (Advanced Transportation Management and Information System) is suggested.

Users proceed with constructing and refining the planning vector. Participants choose ATMIS in which case they must specify the area of influence and diversion method, i.e., whether in-vehicle or out-of-vehicle. Similarly, participants must specify HOV (High Occupancy Vehicle) action in terms of spatial, temporal and user dimensions, after choosing it. The attributes for HOV lanes are its location (start and end nodes from which the length can be derived), number of HOV lanes, whether separated or not, time of HOV operation and vehicle occupancy level (threshold for HOV eligibility).

The performance measures can be chosen directly from a list. Participants must further specify characteristics of the chosen performance measure in terms of spatial, temporal and user dimensions. If, for example, delay is chosen, users must specify where the delays will occur, whether delays are needed by times of day, by user group (age, gender, income) and travel decisions (mode, route).

Participants must choose the environment relevant for the analysis. For example, the project location can be chosen to be a specific county, city, route, intersection, etc. PLANiTS can display a map of the region for visual selection of specific links and nodes.

During the specification process, intelligent advice is available. For example, the action agent using the action base constructs a list of associated actions that enhance the performance of the primary action selected. In the HOV example, these can be the construction of Park-and-Ride facilities, construction of exclusive HOV ramps and flyovers, enforcement, Advanced Public Transportation Systems (APTS) that offers real-time ride-share matching, parking pricing and employer supplied transit and ride-sharing incentives. The expert rules that make the associated action suggestions are based on theoretical and empirical evidence regarding compatibility. The associated actions chosen by the users are then added to the planning vector. Participants must specify the associated action attributes as well. For example, the location, and size of a Park and Ride lot must be specified.

The functions available in PLANiTS are explained below. The analysis of the planning vector, after it is specified, can proceed in several different ways. One way is illustrated. To calculate the performance measures, the analysis agent uses the information contained in the planning vector and suggests the use of cases, expert systems and relevant models. Participants can decide to examine the case-based reasoner. After entering the reasoner, participants adjust the degree of stringency for each element of the planning vector. For example, by choosing “low” action specification, only the cases that have the same primary action are displayed. A “high” action matching specification selects cases with the same numerical values for the action as specified in the planning vector (i.e., the same occupancy threshold and number of lanes in the HOV example). Participants can also provide similar matching specifications for performance measures and environment. Text summarizing the cases in terms of case location, action type and action attributes, performance measures evaluated, methodology used for evaluation and the quality of the case study can be examined. Participants can exclude (or include) cases depending on personal judgement. When participants are satisfied with the similarity of retrieved cases with the current situation, they can calculate the summary statistics. The reasoner calculates the performance measure average for retrieved cases and users can either accept or reject the result. If accepted, the result is attached to the performance measure for possible retrieval later.

Performance measures can also be calculated by using expert systems. For example, using the data on vehicle occupancy, desired HOV occupancy threshold, and desired number of HOV lanes, the expert system calculates travel time savings using simple rules. Users are asked a series of questions: Threshold for traffic congestion (default is 1800 vehicles per hour per lane), minimum threshold for flow on HOV lane (the default is 1000 vehicles per hour per lane based on our review of HOV literature), minimum travel time savings (the default is 1 minute per mile for the HOV lane) and so on. These rules are used to examine whether adding an HOV lane is a good idea. The use of expert rules can help avoid costly analysis and provide a quick and easy way to get answers. If the results are acceptable to the user, they are attached to the planning vector for use in debate and deliberation.

After having examined the case-based and rule-based reasoners, participants may wish examine the model-based reasoner. Participants can choose to run the models that have been located by the analysis agent, based on the information contained in the planning vector. When a specific model is chosen, participants are presented with the data requirements for that model. If the required data are available, then the model run can proceed (availability of data is ascertained internally based on the environment vector specification). If the data items are not available, then participants can either input the unavailable items or return to the planning vector and re-specify the environment vector. After the model runs, the results, in terms of change in performance measures due to the action, are displayed. PLANiTS also can display the results from two separate planning vectors, so they can be compared and discussed.

The planning vector is considered assessed (by using models, cases or expert systems) when the selected performance measures have been calculated. The assessed planning vector can be shared (the vector is duplicated on other computers elsewhere) among participants working on separate computers. In addition, participants can send and receive messages, debating various aspects of the assessed planning vector. The discussion list keeps a track of the communications. A discussion about the results might spawn a reevaluation of the planning vector. Finally, the session is terminated when all parties achieve consensus or resolution.

In the long term, PLANiTS will learn from the participants' working patterns and preferences and develop new rules to support the planning process.

3. PLANiTS FUNCTIONALITY

Below we summarize the loosely followed steps in PLANiTS prototype development. To construct the internal structure of PLANiTS, we identified the following tasks:

- Develop lists of actions (and associated actions), measures of performance and environments. We selected a few for inclusion in the prototype based on our judgement, availability of resources and current and future relevance to transportation planning. The actions selected were High Occupancy Lanes (Desevaux 1993; Malgat 1993; Dahlgren 1994) and Advanced Transportation Management and Information Systems (Khattak, Al-Deek, Paramsothy 1994). The measures of performance include delay, travel times and air quality. The environments were restricted to the Bay Area.

- Develop a structure for representing actions, performance measures and environments. Specifically, they can all be specified in terms of spatial, temporal and user dimensions.
- Choose existing models that can be integrated in the PLANiTS environment. A current planning model (Minutp) was chosen largely because the local Metropolitan Planning Organization (MPO), the Metropolitan Transportation Commission (MTC), uses the model; a widely used traffic operations model (FREQ--a freeway simulation model) and a newly developed route diversion ATMIS model (CombehQ[1]) were chosen largely due to their availability.
- To demonstrate the concept of the knowledge base, we developed a simple rule-based expert system for the HOV example. In addition, we developed the case-based reasoner using hypothetical data for HOV and ATMIS actions.
- Select team and task decision support tools that are demonstrable on a limited scale. These include commenting and sharing the planning vector.
- Have the ability to evaluate options and compare them visually and if possible in a common metric.
- Demonstrate "intelligence" in the system.

The following sections elaborate the design and the functionality of the PLANiTS prototype along with planned enhancements.

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[1]CombehQ simulates incidents that occur on a two-route corridor and incorporates realistic behavioral route diversion rules (see Khattak et al. 1993 for details). The inputs are percent equipped with ATIS, freeway capacity and free flow travel time, alternate route capacity and free flow travel time, incident duration, incident reduced capacity and total demand. The model uses deterministic queuing theory to calculate the benefits of implementing ATMIS in terms of reduced delay. The model simulates several randomly generated incidents.

3.1 Policy and Goals Base

As mentioned earlier, the Policy and Goals Base contains mandates, objectives and constraints communicated in terms of appropriate policy factors to be satisfied and measures of performance to be selected. It also contains a set of rules that link policies to performance measures and actions. The overall objective is to help participants select and refine performance measures. The planning agent, using the policy and goals base, constructs a list of performance measures. The specific functions of the Policy and Goals Base essential for the prototype are:

- *Performance Measures.* There is a hierarchical list of high-level performance vectors (congestion, safety, air quality, accessibility, economic efficiency) and lower level more specific performance measures (under congestion, delay, travel time, etc.). Participants can select a specific performance measure (e.g., travel time or delay) and add it to the planning vector.
- *Performance Measure Specification.* After selecting a performance measure, the participant can specify various aspects of the measure. For example, if delay is chosen, then participants specify the network where delay is needed, whether it is recurring or non-recurring, time unit (on annual or daily basis, peak or off-peak basis), the user group (whether delay is needed by age group, gender, etc.), user unit (by passenger or vehicle), trip characteristics (by trip mode, trip purpose).
- *Policy Factors.* These are operationalized policy factors that participants can check to ensure that the project is policy relevant. In the prototype, ISTEA "fifteen factors" must be operationalized. The simple rules used to give intelligent advice are:

Rule		*Simplified Example*
IF	Policy factor of interest = $\{p_i\}$	{ISTEA, congestion relief)
THEN	Performance measure = $\{y_i\}$	{delay}

In the future, these rules will be extended to current policies and performance measures suggested by the local MPO, for example.

- *Suggest Actions.* Participants can request for actions that address certain goals. A simple example is the following rule:

Rule		*Simplified Example*
IF	Goal= $\{\mathbf{g_i}\}$	{congestion reduction}
THEN	Actions to be considered = $\{\mathbf{a_i}\}$	{HOV}

Participants can ask for actions that will appropriately address certain policy factors, meet certain requirements, or redress violations.

Rule		*Simplified Example*
IF	Policy factor = $\{\mathbf{p_i}\}$	{IVHS}
THEN	Actions to be considered = $\{\mathbf{a_i}\}$	{ATMIS}

In addition, policies will link actions with associated actions.

- *Conformity.* Participants can check for compliance. PLANiTS may invoke the following rule:

Rule		*Simplified Example*
IF	Policy factor of interest = $\{\mathbf{p_i}\}$	{ISTEA, congestion relief}
AND	Action = $\{\mathbf{a_i}\}$	{HOV}
AND	Performance measure = $\{\mathbf{y_i}\}$	{Emissions}

AND	Environment = { e_i }	{XYZ}
AND	Performance Measure Evaluated = { y_i* }	{not null}
AND	(Base Emissions - "After" HOV Emissions) > 0	
THEN	Inform users about conformance	
ELSE	Warn users about increase	

The following functions of the Policy and Goals Base are planned for inclusion in PLANiTS:

- *Violations.* Participants can ask for violations of policy requirements at project location. This brings up a display of the locations where, for example, the air quality requirements are being violated. The valid responses are to check for air quality, congestion, safety, accessibility. PLANiTS then provides a display of performance measures currently being violated at the project location.
- *Requirements.* Participants can ask for requirements or restrictions due to policies and mandates. This brings up a map that displays, for example, the air quality requirements in the future at the project location. Moreover, participants could turn the requirements into constraints that must be satisfied through analysis.
- *Performance Measures.* Relevant to the implementation of new technology actions is the development of "action-specific" performance measures. Suppose that implementation of ATMIS is being considered. The expected frequency of congesting alternate routes due to information dissemination is an action-specific performance measure that can be included for analysis in PLANiTS. Importantly, users should be able to add their own performance measures and assumptions to conduct analysis in PLANiTS.

- *Funding Sources.* Participants may request for availability of funding from various sources. Funds of interest can include Surface Transportation Programs, Congestion Management and Air Quality, Flexible Congestion Relief and ISTEA and any residual funds from previous years.
- *Show Policy.* This shows the summary text of a policy such as ISTEA or Clean Air Act. The important policy features will be summarized in figures and tables.
- *Show Mandates.* This shows the summary text for mandates that are specific to the region and also the results of any relevant rulings.
- *Add Policy, Delete Policy.* The users can input information about the mandates and other requirements as they come into effect. This will require establishing or severing the necessary links with other bases.

To develop the policy and goals base further, we need to operationalize all existing policies into a set of rules that provide checks, requirements, violations, constraints and funding opportunities. A complete fact-list (set of rules) and inference engine (logic that controls the overall execution of rules) will be available in future versions.

3.2 Strategy and Action Base

The Strategy and Action Base contains a set of actions that increase transportation supply, reduce demand, increase accessibility or otherwise improve system performance, as well as sets of supportive actions that would enhance the effectiveness of the primary action, and competitive actions that tend to diminish its effectiveness. Also, there are alternative actions. The overall objective is to help participants select and refine actions. The planning agent using the strategy and action base constructs a list of actions and associated actions. The specific functions are:

- *Actions.* There is a hierarchical list of high-level actions (roadway, transit, bicycle/pedestrian, intermodal/freight) and lower level more specific actions (e.g., under roadway action, HOV lanes or ATMIS). These can be selected and added to the planning vector.

- *Action Specification.* Participants can specify action attributes. If ATMIS is chosen, then participants specify whether it is in-vehicle or out-of-vehicle, the data collection method (loop detectors or infra red beacons) and so on.
- *Associated Actions.* Participants can ask for associated or complementary actions. A list of associated actions appears and participants can add the appropriate ones to their planning vector. The logic is based on the action-interaction matrix (Kanafani et al. 1994). The matrix is used to form rules such as:

Rule		*Simplified Example*
IF	Action selected = $\{\mathbf{a_i}\}$	{HOV lane}
THEN	Associated action $= \{\mathbf{a_{j|i}}\}$	{Advanced Public Transportation Systems I HOV lane}

The following functions of the Strategy and Actions Base are planned for inclusion in PLANiTS:

- *Suggest Performance Measures.* Participants can request for mandated or MPO recommended performance measures that will be appropriate for actions of interest. A simple example is the following rule:

Rule		*Simplified Example*
IF	Action = $\{\mathbf{a_i}\}$	{HOV}

THEN Performance measures = $\{\mathbf{p_i}\}$ {delay, emissions}

- *Action Requirements.* Participants can request for action attributes that can address requirements or restrictions due to policies and mandates.
- *Add Actions, Delete Actions.* Participants can input relevant information about new actions that might be available to them.

To develop the action base further, we need to collect and examine empirical evidence regarding action interactions. Particularly, there is a need to find out what actions can successfully address requirements or restrictions due to policies and mandates and redress violations of policy requirements.

3.3 Data and Knowledge Base

The data and knowledge base contains layers of data at various levels of information and knowledge content. Methods of case-based reasoning and rule-based reasoning are used to convert the data into relevant knowledge.

3.3.1 The Data Base

The data base stores and accesses disaggregate data on peoples' activity participation and travel patterns as well as aggregate data on transportation system performance. The objective is to help participants define the boundaries of their project. The analysis agent uses the data base to provide needed input to models. Specific functions essential in the PLANiTS prototype are:

- *Environment.* There is a list of environmental descriptors for the project consisting of spatial, temporal and user dimensions. These form the base input data for running models. Typically the user will select a network (e.g., East Bay, San Francisco) or a particular highway (Interstate 80 between x any y nodes), the times when the analysis must be conducted and the users. Notice that some of these specifications may overlap with action and performance measure specification and may be avoided.

- *Environment Specification.* Participants can select links and nodes directly from a map.

The following functions of the data base are planned for inclusion in PLANiTS:

- *Query.* Users can request information contained in the PLANiTS data bases. Participants can specify the data they wish to examine and the calculations or operations that they want to perform. The result of a query will be available as text of in a table.
- *Sort.* The data base will provide the ability to sort data in ascending or descending order.
- *Other functions.* Users could insert and delete new records, create new fields and change attribute values.

3.3..2 The Case Base

Case-based reasoning (CBR) uses experiences with previously implemented actions and evaluations to address new planning situations (Kolodner 1993). The overall objective is to help participants analyze the planning vector by retrieving and displaying similar cases from the case base. Similar cases allow users to draw inferences regarding values of performance measures in the current context. The specific functions are:

- *Evaluate by case.* There is an evaluation option that takes the user to the case-based reasoning module where he or she can begin the case retrieval process.
- *Adjust Stringency.* Users can adjust the degree of similarity required for matching cases to the current planning vector. The Case Planning Vector (CPV) is an adaptation of the regular PV that also allows participants to select actions, performance measures and

environments at three levels of specificity. That is, the case planning vector treats the current planning vector as the new inputs (current case) and allows participants to select among three stringency levels.

0 *Low Match.* The matcher provides a listing of similar cases by accessing them through the index. This brings up a list of cases that are broadly similar in terms of planning vector elements. Participants can select a low level of similarity on actions, performance cluster and environment and the case-based reasoner will retrieve cases that deal with the specification. For example, if action is HOV, performance cluster is congestion and environment is within the United States, then all cases that satisfy these criteria are retrieved.

0 *Medium Match.* The matcher uses a higher stringency level. It is based on a subset of numerical action attribute values. For the HOV example, cases with the same number of HOV lanes are retrieved. The environment becomes restricted to the State (of California). If the performance measure is travel time savings, then cases that are not null are retrieved. Similarly, if ATMIS is selected, then cases are retrieved if they have the same device type (in-vehicle or out of vehicle).

0 *High Match.* This brings up a list of relatively fewer cases that highly are similar at a greater level of specificity. The matcher uses all numerical information available about elements of the planning vector to select cases. For example, if the action is HOV, then retrieved cases will have the same number of HOV lanes, the same time of operation (plus/minus some limit), the same occupancy threshold and length. Similarly, the environment criteria are more stringent, i.e., in the prototype, only Bay Area HOV cases are selected.

Summaries of the selected cases are displayed. The cases are reexamined each time the stringency is adjusted and only the matching cases appear in the list.

- *Show Case.* This function gives detailed textual descriptions of the cases.

- *Remove Case.* Cases are removed from the list if the user so chooses. This allows users to exercise judgement over case similarity.
- *Accept.* After participants examine the cases and are satisfied with their similarity to the current situation, and the case performance measures, they can accept the case. This means that the case performance measure outcomes are averaged and saved as the answer. Future versions of PLANiTS will perform more elaborate analysis on cases.

The following functions of the Case-Based Reasoner are planned for inclusion in PLANiTS:

- *Compare.* The function allows a comparison of the current case (i.e., participant specified planning vector) with the selected retrieved case(s) in a table. The cases are compared visually in terms of their action attribute values, performance measure sub-cluster values and Environment.
- *Rank.* The retrieved cases are ranked in terms of their similarity with the current case. Summaries are ordered according to a Similarity index, which is a combination of the weighted action attributes, and environmental factors will be used to rank cases.
- *Analyze.* Initially, the analyzer may provide summary statistics including mean, median, minimum and maximum for selected cases. Later more advanced statistical models will be added. If predictions are required and several relevant cases are retrieved, then the analyzer would provide predictions by compiling evidence from the cases.
- *Resolve.* The resolver will resolve differences between a retrieved and current case. If participants want to use a case for prediction, then they can adapt it. For example, the performance measure estimate of a retrieved (HOV) case can be adjusted (delay estimate lowered) to account for differences between the two cases (length and times of operation).
- *Review.* A reviewer would provide "sanity checks" and veto a match or provide warnings

about the extent of (in)compatibility.

- *Advise.* A prescriptive reasoning mechanism will rely on rules such as do not recommend actions that are "double edged swords."
- *Assimilate.* After an action is evaluated in PLANiTS, an assimilator will automatically acquire and store the information for future use.
- *Other-functions.* Other functions include, delete case, modify case (attributes) and show case (display all case attributes).

To develop the case-based reasoning mechanism further, the elaborate architecture suggested above will be used. Cases collected from literature, experts and field operational tests, will be stored and indexed according to actions, performance measures and the environment as well as other criteria.

3.3.3 The Expert Base

Rule-based reasoning (RBR) uses refined and filtered knowledge accumulated from previously implemented actions and evaluations to address new planning situations. RBR relies on theoretically plausible and empirically valid rules. It can advise on the feasibility of a specified action by using rules. The objective is to help participants analyze the planning vector by using expert modules that deal with specific actions. To demonstrate the use of an expert system, a simple expert system described below was developed (in a fully developed PLANiTS, participants will typically select among several relevant expert systems identified by the analysis agent). The specific Rule-Based Reasoning functions are:

- *Evaluate by Expert Rules.* The selection allows the use of expert systems.
- *Run Expert System.* The data needed to begin the expert system are located. If all required data items are available, then users can proceed with running the expert system. For the

HOV example, the inputs consist of physical data (number of mixed flow lanes and number of HOV lanes, HOV lane length) and traffic data (percent of vehicles with 1, 2, 3 and 4+ passengers). The answers are based on speed flow relationships and rules such as, if eligible HOV vehicles use are more than the capacity of the HOV lane (1800 vehicles per hour per lane), then adding one HOV lane is not helpful.[2] If travel time savings offered by HOV lanes are greater than a threshold (one minute per mile), then significant mode shift to HOV is expected. If HOV lanes are longer than a threshold (e.g., two miles), then they are likely to reduce traffic congestion (exceptions are bridges and bottleneck bypasses).

- *Show Results.* The results are displayed either numerically (e.g., average speed, travel time per passenger, or per vehicle for HOV and mixed flow lanes) or textually (the action specification will not produce travel time savings in the current context). After participants examine the results and are satisfied, they can accept them.

In future PLANiTS versions, we will include the browse function that allows participants to watch the firing of rules in the expert system. To develop the rule-based reasoning system, a more elaborate research effort is needed. Developing new expert systems is costly and time consuming, yet there is value in organizing and synthesizing transportation knowledge.

3.4 Methods and Tools Base

The Methods and Tools Base uses state-of-the-art models at various levels of specificity to evaluate actions. It relies on the concept base that identifies and recommends appropriate models for a specified planning vector. Transportation planning and operations models are contained in the model base. The objective is to help participants analyze the planning vector by identifying models and their input requirements. The analysis agent, using a set of analysis processes and

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[2] Ms. Florence Desevaux has developed a mathematical formulation to estimate travel time savings due to HOV lanes.

rules, evaluates impacts of action by running models with data available in the environment vector. The base also contains a set of generic models for statistical analysis and network performance assessment. The specific functions of the Methods Base are:

- *Evaluate by Model.* The evaluate function brings up a list of possible models that can evaluate the specified planning vector. The search for models is done based on actions and performance measures in the planning vector. For example, FREQ and Minutp are located for evaluating HOV lanes in terms of delay. When there are no available models, participants may use generic tools to develop their own models.
- *Data Requirements.* After a model is chosen, the data requirements to run the model are evaluated internally. If the data items are available in PLANiTS, then the user may run the model. If the data items are not available, then the participant can either input them or go back to the planning vector and re-specify the environment vector to take advantage of available data bases.
- *Run Model.* If all required data items are available, then the model can be run.
- *Show Results.* The results are displayed in tabular or textual form and often show the change in performance measure with and without the action.
- *Compare.* The outputs from evaluation of two actions can be compared, e.g., in terms of percent change from the base or do nothing alternative. If the results are not in a common metric, it can spawn off a reevaluation of one or both planning vectors.

The following functions of the Methods and Tools Base are planned for inclusion in PLANiTS:

- *Generic Tools.* There will be a list of various generic tools that could be statistical models, econometric methods, optimization techniques and artificial intelligence methods. The purpose is to provide participants the capability to develop new models where none are available. Furthermore, the generic models should be chained to form a sequence of models that can address new technology evaluation issues.

- *Model Advisor.* A larger role is envisaged for the mechanism that locates and recommends appropriate models. The following rule elaborates this:

Rule		*Simplified Example*
IF	Goal $= \{\mathbf{g_i}\}$	{Improved Air Quality}
AND	Policy factor of interest = $\{\mathbf{p_i}\}$	{ISTEA, Environmental effects of transportation decisions}
AND	Measures of Performance = $\{\mathbf{y_i}\}$	{Carbon-Monoxide}
AND	Environment = $\{\mathbf{e_i}\}$	{ABC county}
AND	Action selected = $\{\mathbf{a_i}\}$	{add HOV lane}
AND	Associated actions selected $= \{\mathbf{a_{j\|i}}\}$	{Advanced Public Transportation Systems I HOV lanes}
THEN	Use models $= \{\mathbf{m_{j\|i}}\}$ with Data $= \{\mathbf{d_{j\|i}}\}$	{Run models XYZ using data on transit statistics and origin destination from ABC county}

- *Compare.* Currently we use a common base (0, 0) for comparison of two actions Al, A_2. The comparison can become complicated if additional comparison bases (A_1, 0) and (0, A_2) are needed or if implementation sequence of actions influences the values of performance measures (Al, Az-? A_2, Al). The alternative bases issue is important because often new technology benefits must be evaluated over and above precursor technology benefits, e.g., additional ATMIS benefits over radio traffic information benefits.

- *Browse.* There are varying degrees of accuracy in models and data input to models. People are unaware of the extent of model accuracy and assumptions. Therefore, providing participants information about error and uncertainty of estimates would be useful.
- *Explore Models.* This function allows users to run models outside the planning vector context. This would encourage experimentation with the models. The function will be useful for forecasting testing model sensitivity to input parameters and comparing different models.
- *Model Chuiner.* This will chain two models together. For example, by providing the capability to use outputs from one model as inputs to another complex transportation situations can be analyzed.
- *Model Assimilator and excluder.* This function gives the option of adding or removing models and data transformation rules (e.g., aggregation rules). Adding a model requires that setting the necessary links to existing analysis processes. Removing a model requires that links to the model in the complex web are properly severed.

The development of model base is complicated because the current transportation models have been developed to function independently rather than in a unified environment. We hope that PLANiTS will become a unifying platform for various transportation models. We are also developing methods for comparing the output from planning and operations models in a common metric.

3.5 Human Interactions

Participant interactions are supported through a computer-based intelligent facilitator. It allows participants to work with the system and each other in an interactive on-line environment. The computer support for such processes comes from using tools that allow sharing of information, group evaluations, personal work support and intelligent agents. The overall objective is to help participants interact. The interaction could take several forms including brainstorming, goal setting, problem definition, and generation of alternatives using techniques categorized as team and task support systems (Vlahos, Khattak, Kanafani, Manheim, 1994). The other function, consensus building and resolution seeking, supports the weighing of tradeoffs, making of compromises, compensation of losers and final decision-making,

The development of human interaction support mechanisms will allow multiple participants to work together by exchanging information that includes components of the planning vector. The techniques of group decision support are used by participants throughout the process of creating evaluating planning vectors. The group decision support techniques are:

- *Share Planning Vector.* A planning vector can be shared with other participating machines in a PLANiTS session. Each vector that is shared based also appears on the other machine with the same name and all copies of the vector are kept updated. Any.changes made to a shared planning vector on one machine also appear on other machines. The function must protect non-shared or private planning vectors.
- *Send/receive Message.* Participants can pass messages electronically across linked machines. Notes on any topic can be sent to all other participants. They must be listed in the order they are received. The messages can be sent to a sub-set of participating machines. They should also be able to reply to specific messages, thread messages and their replies and associate messages to particular planning vectors. The message passing mechanism could turn in to a sophisticated electronic mailing system with special features that deal with the planning vector.

The following functions of the group decision support techniques are planned for inclusion in PLANiTS:

- *Information sharing.* Various information sharing tools include electronic brain storming for generating ideas, threaded discussions, group dictionary, and collaborative writing.
- *Group evaluation.* The functions include classification and categorization of issues, ranking, voting and scoring.
- *Communications.* Such functions include tele-conferencing and chatting.
- *Meeting management.* These include access control, team definition/assignment, deadline management.
- *Intelligent agents.* The tools include automatic mail processing and rule-based routing of information.

The most important tools that will be necessary building blocks in the transportation planning context are identified in Vlahos, Manheim, Xie (1994). Programming these functions into PLANiTS will require a relatively large effort. Alternatively, we could directly use some of the functionality available in existing group decision support tools such as LOTUS NOTES.

3.5.1 Designing a Method to Complete a Project

In future versions, participants can use certain utilities to design their own strategy to complete a project. There are often local MPO and federal requirements for completion of projects. The requirements will be translated into questions and checks that can be used to ensure that the project is sound. These set of questions could be a utility that inspects the project and tells project weaknesses. For example, users can be asked the following questions:

Policy requirements

- Does the project meet ISTEA mandates?
- Does the project include an air quality document?

- In case it is a road project, does it include call boxes specified according to American with Disabilities Act?

Consistency requirements

- Did the project bring all players to table, (i.e., transit operators, cities, counties, CMAs, State Department of Transportation, Air Quality Management Districts, ports and airports, interested citizens and groups)?
- Did the project encourage public participation?
- Is the project consistent with Regional Transportation Plan requirements?
- If it is a boundary project, then is it consistent/complimentary with adjacent county?

Project-specific requirements

- Is the project well defined in terms of project limits, scope, concept and justification?
- Does the application include the standard form(s)?
- Does the project have proper phasing, (in case it is a highway project, then it must include appropriate components of Traffic Operations Systems such as ramp metering, HOV bypasses of meters, Changeable Message Signs)?

Financial requirements

- Is the project within reasonable limits set by availability of projected funds?
- Does it have reasonable cost estimates?
- Does it include local contributors?

The answers to these questions can send the users through iterations in the PLANiTS process. Some of these questions will be absorbed into various bases of PLANiTS.

3.5.2 Intelligent Guidance Functionality

There will be separate module in PLANiTS that can provide guidance on developing the planning vector (also see Vlahos 1991).[3]

- *Planning Vector Goals.* There is a list of planning vector goals. An example is "generate feasible planning vectors" or "modify existing planning vectors." The user can choose one of these goals.
- *Strategies.* Participants are provided with a set of strategies that can be used by intelligent agents to address solution goals. Users can select the plan or strategy and receive information about the strategy. A strategy that addresses the first planning vector goal is to "create a new planning vector with A actions, Y performance measures that are not part of any planning vector yet." For the second planning vector goal, a strategy can be to "modify the current planning vector with A_1 actions that are not part of any planning vector yet" or "add one roadway action to all existing planning vectors." This last strategy may have several instances. In one instance, it may result in adding an HOV lane. In another instance, it may mean adding ATMIS to the planning vector.
- *Guidance on Planning Vector options,* The execution of advise results in suggestions for modification to the existing planning vector or creation of new planning vectors.

3.6 Non-Functional Requirements

There are a set of operating constraints and standards that PLANiTS should meet. An important constraint in integrating existing models is that they are not designed to work within the same environment. Also, there should be limits on maximum response times for running models. Furthermore, PLANiTS must be user friendly and incorporate automatic error checking.

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[3]Dr. Nicholas Vlahos contributed toward developing the intelligent guidance idea.

4. SUMMARY AND FUTURE RESEARCH

We have presented a functional view of PLANiTS. The development was largely iterative, with much back and forth between conceptual design, functional specifications, software design and implementation. Future versions of PLANiTS must incorporate PLANiTS components on a larger scale. It should be capable of use in a real-life planning environment. Specifically, participants should be able to evaluate several more actions (in addition to HOV lanes and ATMIS) and their interactions using cases, expert rules and models.

We see our efforts as the beginning of a new planning methodology that seeks to be open, policy relevant and allows participants to examine tradeoffs in an interactive environment. It also enhances creativity in exploring innovative solutions such as IVHS by integrating structured models, with semi-structured evaluation such as cases and expert systems and unstructured electronic support for human interactions.

We have taken the first steps toward developing a transportation data structure reflected in the specification of performance measures and actions. Using the structure, we can unify various disaggregate and aggregate analysis in the future.

We hope to follow a two tiered approach to PLANiTS development: First, to develop a fully functional PLANiTS in close consultation with the users. Second, to conduct theoretical and empirical research in the areas of collaborative and antagonistic teams, information theory, data filtering, intelligent data bases, case-based reasoning, expert systems, model transferability, and new technology impacts.

Ultimately, PLANiTS may not change the political process, however, its contribution could come from enabling people to avoid at least some potential minefields and costly mistakes.

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