Long Range Deployment of ITS Strategies: Concept Definition

Project 02 – 04
February 2003

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EXHIBIT B

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No. **CFDA 20.701**
4. Title and Subtitle **Long Range Deployment of ITS Strategies: Concept Definition**		5. Report Date **February 28, 2003** 6. Performing Organization Code
7. Author/s **Alan J. Horowitz, Juan Duarte, Andrew Cross**		8. Performing Organization Report No. **MRUTC 02-04**
9. Performing Organization Name and Address **Midwest Regional University Transportation Center** **University of Wisconsin-Madison** **1415 Engineering Drive, Madison, WI 53706**		10. Work Unit No. (TRAIS) 11. Contract or Grant No. **DTRS 99-G-0005**
12. Sponsoring Organization Name and Address U.S. Department of Transportation Research and Special Programs Administration 400 7th Street, SW Washington, DC 20590-0001		13. Type of Report and Period Covered **Research Report 11/01 to 3/03** 14. Sponsoring Agency Code
15. Supplementary Notes **Project completed for the Midwest Regional University Transportation Center with support from the Wisconsin Department of Transportation.**		
16. Abstract **This report deals with the issue of how ITS (Intelligent Transportation Systems) strategies and technologies should be implemented over a long period of time (e.g., 10 to 20 years). Many strategies can be identified that have long-range implications, and a few of these strategies are particularly relevant to deployments in the US Midwest. Described are eight classes of traffic engineering and transportation planning software that show at least some promise for forecasting the benefits of ITS deployments. Reviews are given for four exemplary packages so that an assessment can be made about the advantages and disadvantages of existing analytical tools. The state of the practice of strategic (short-range) ITS deployment is also reviewed. Information drawn from a variety of agency reports reveals that a unified procedure for strategic ITS planning can be developed and may be amended for long-range ITS planning. However, to properly amend strategic ITS planning for long-range deployments, it is necessary to have substantially upgraded analysis tools. This report recommends the development of a dynamic travel forecasting model (DTFM) for this purpose. A prototype DTFM is shown to be able to optimize the long-range deployment of incident management. Factors needing special consideration when performing long-range ITS deployments include (1) developing appropriate scenarios and alternatives; (2) establishing a good staging process; (3) optimizing the use of assets; (4) involving stakeholder input at the appropriate times in the process; (5) recognizing randomness in the traffic system; and (6) properly accounting for changing technology.**		
17. Key Words **ITS** **Intelligent Transportation Systems** **Long-range** **Deployment** **Optimization**	18. Distribution Statement **No restrictions. This report is available through the Transportation Research Information Services of the National Transportation Library.**	

19. Security Classification (of this report) **Unclassified**	20. Security Classification (of this page) **Unclassified**	21. No. Of Pages **103**	22. Price **-0-**

Form DOT F 1700.7 (8-72) **Reproduction of form and completed page is authorized.**

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February 28, 2003

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Executive Summary

A considerable amount of effort in the past has been devoted to developing methodologies for short-range ITS deployment. This report deals with the issue of how ITS (Intelligent Transportation Systems) strategies and technologies should be implemented over a long period of time (e.g., 10 to 20 years).

This report addresses the following questions:

- Are there many ITS strategies that have long-range implications and, if so, which of the strategies have greatest relevance?
- Is there a consensus as to the best way of performing strategic ITS deployment planning? What features of strategic ITS planning should be retained for long-range ITS planning?
- What is the status of software tools for investigating the effects of ITS deployment over the long range? Can existing software tools be successfully used in long-range ITS deployment planning? How can those software tools be improved to provide better evaluations of ITS deployment plans? What are the obstacles?
- Can a workable methodology for long-range ITS deployment planning be demonstrated?
- What conclusions can be reached about long-range ITS deployment planning?

Are there many ITS strategies that have long-range implications and, if so, which of the strategies have greatest relevance?

A review of all ITS strategies in the National ITS Architecture CD-ROM found twelve important strategies that had long-range implications. Of these twelve strategies only a few are of particular relevance to transportation engineers in the Midwest region. The following three items provide a more focused set of strategies.

A. Integration of the network signal systems control with the controls of freeways. This item would also include elements of the control of traffic signalization, principally area wide.
B. Management of scheduled/planned incidents (including traffic spikes from special events).
C. Pre-trip and en route information to assist travelers in making mode choices, travel time estimates and route decisions prior to departure. This item would also include control of dynamic traffic signing (including the signs) and en route driver information that facilitates the choice of alternative routes.

These particular strategies served as reference points for the evaluation and formulation of tools for long-range ITS deployment assessment in the rest of the report.

Is there a consensus as to the best way of performing strategic ITS deployment planning? What features of strategic ITS planning should be retained for long-range ITS planning?

A review of many strategic ITS plans revealed that a complete planning effort should involve the following elements.

- Identify User Needs
- Establish Goals
- Recognize Conventional Approaches
- Establish Objectives
- Identify Candidate ITS Strategies
- Conduct a Selection Process
- Elicit Stakeholder Input
- Prepare Deployment Plan Including Alternatives
- Measure Criteria by MOEs (Measures of Effectiveness) and Other Assessment Means

Long-range ITS deployment planning should contain the same elements as strategic ITS deployment planning, but it must also recognize the peculiarities of forecasting traffic conditions many years into the future.

Scenarios and Alternatives. In order to correctly identify staging, long-range ITS planning involves a time stream of scenarios, each one is a consequence of its immediately prior scenario. An ITS alternative make sense only within the context of a scenario.

Staging. A complex staging process may be required for good long-range ITS plans. This complex staging recognizes that (1) earlier years have ITS and conventional infrastructure that is worth preserving and (2) travel patterns may have been altered because of alternatives selected in an earlier year. Such a complex staging process would be difficult to accomplish manually and would be greatly facilitated with specialized software that optimizes the deployment in any given year. A simple example of a variable message sign deployment illustrates how complicated the staging process can become.

Optimization Multiple Criteria and Grandfathering. Almost all long-range transportation plans are based on multiple criteria, such as travel time savings, safety, air pollution emissions, capital costs and maintenance costs. The method by which multiple decision criteria within an optimization framework is handled is critical to the results. Grandfathering is a form of a constraint on the optimization by specifying that certain ITS elements must be selected in a given year.

Stakeholder Input. Stakeholder input assures that the alternative is technically feasible, but getting adequate stakeholder input during an automated choice process would be very difficult. Stakeholder input can occur only at the beginning (proactive) or end (reactive) of the process. Essential proactive stakeholder input includes:

- Cost data on deployment alternatives, both fixed and variable, and projections as to how costs may decline with time;

- The degree to which grandfathering needs to be respected;
- Estimated availability dates on technologies;
- The life span of candidate technologies and equipment and depreciation rates;
- Constraints on deployment;
- Logical arrangements of elements;
- Synergies between various elements;
- Performance characteristics of elements; and
- Opinions as to the best way to represent the performance of an element in software.

Recognition of Random Situations. A strength of ITS is the ability to respond to unusual events, often random. The standard method of benefit-cost analysis to dealing with random situations is to find the "expected benefit" by weighting the benefits of a deployment with a random situation by the probability of that situation occurring. Similar reasoning applies to costs of random situations.

Costs and Technologies. It is well known that the costs of communication and information technologies decline with time, so it is may be necessary to make costs of deployment a function of time, which can improve the cost effectiveness of certain ITS options in the later years of the plan.

What is the status of software tools for investigating the effects of ITS deployment over the long range? Can existing software tools be successfully used in long-range ITS deployment planning? How can those software tools be improved to provide better evaluations of ITS deployment plans? What are the obstacles?

There are eight classes of simulation software packages that can help evaluate long-range ITS deployment plans. They are:

- Traffic Microsimulation
- Mesoscopic Traffic Simulation with Dynamic Traffic Assignment
- Macroscopic Traffic Simulation
- Traditional Four-Step Travel Forecasting with Static Traffic Assignment
- Travel Demand Microsimulation
- Hybrid of Four-Step with Traffic Microsimulation
- Four-Step with Integrated Macroscopic Traffic Simulation
- Specialized Static Traffic Assignment for ITS Evaluation

A comparison of the general characteristics of these classes of tools indicated that four classes had the greatest potential for simulating long-range ITS strategies. A single software package representing each of these four classes was reviewed for meeting the needs of the problem. They were IDAS (specialized static traffic assignment for its evaluation), QRS II (four-step with integrated macroscopic traffic simulation), Paramics (traffic microsimulation), and Dynasmart-P (mesoscopic traffic simulation with dynamic traffic assignment). Each of these packages has its separate strengths and weakness and none is currently suitable for long-range ITS deployment. All of the packages share several weaknesses:

- *Staging.* None of the software packages is able to simulate a sequence of deployments, where the decisions in some distant future year are dependent upon outcomes in an earlier future year.
- *Realism of Traffic Simulation across a Wide Spectrum of ITS Strategies.* No software package exists that can correctly simulate (according to accepted traffic flow theory or theory of travel behavior) a wide spectrum of ITS strategies.
- *Alternative Selection.* None of the software packages is able to choose an optimal combination of ITS elements (or even a reasonably good combination).
- *Adaptiveness.* The software packages, for the most part, are not adaptive beyond allowing for actuated signals. That is, the software packages cannot make many of the routine and rationale judgments that a traffic engineer would make.
- *Optimization of Traffic Operation.:* None of the software packages optimize the operation of existing facilities or traffic controls within those facilities.
- *Random Effects.* None of the models, with the possible exception of single, isolated incidents in Paramics, adequately addresses random effects.

Many of the weaknesses in individual packages may be overcome by combining the best parts of several software packages. The resulting package might be referred to as a dynamic travel forecasting model (DTFM). An experimental DTFM was constructed for this project by modifying the source code of QRS II to include essential algorithms of Dyasmart-P. A few lessons were learned from building the DTFM. (a) No serious compromises need be made to combine the methodologies. (b) Computation times are greatly increased over a traditional travel forecast, but computer hardware requirements are essentially the same. (c) Since a DTFM creates its own origin-destination tables, this difficult input requirement of a dynamic traffic assignment is eliminated. The DTFM can be embedded within an optimizing framework.

Can a workable methodology for long-range ITS deployment planning be demonstrated?

Two different approaches are demonstrated for modeling the long-range deployment of ITS strategies: (1) the use of a DTFM embedded within an optimizing computer program in order to choose the locations for freeway incident management; and (2) the use of an existing computer program (IDAS) to find a reasonable sequence of ITS deployments.

An optimal long-range freeway incident management plan was automatically created for the smallish Utown test network by repeatedly running the DTFM. Among the 124 links in this network, 12 links constituted almost the entire mainline freeway. After accounting for stakeholder input, it was possible to reduce the number of possible alternatives to 21, including the null alternative. Each alternative consisted of a set of contiguous freeway segments to receive incident management. In each of four planning years, separated by five calendar years each, all 21 alternatives were evaluated to determine whether user benefits exceed the costs of operating the incident management program. In order to evaluate the benefits of incident management it was necessary to individually simulate the effects of a large number of incidents (both managed and unmanaged) and consider the probability that any one of the incidents would occur. Traffic volumes were assumed to grow through time. The optimization/simulation demonstrated the technical feasibility of using a DTFM to evaluate ITS deployments and the advantages of incorporating stakeholder input into the process at the earliest stages of the planning process. The optimization/simulation also demonstrated how growth in traffic can affect the design of ITS strategies and affect user benefits associated with any given strategy.

In a separate set of simulations, a long range ITS deployment plan was created for the full-sized Cedar Rapids network using IDAS, an existing computer program developed for the Federal Highway Administration. IDAS does not automatically design ITS strategies, so it was necessary to develop all possible strategies using engineering judgment before letting IDAS choose the best strategy in any given planning year. IDAS cannot automatically consider combinations of strategies, so each strategy was separately evaluated in each planning year. As strategies were selected, they were grandfathered into all future year plans. Thus, strategies accumulated over time. Using IDAS in this way produced a plausible deployment plan, but it is difficult to tell if the plan is even close to being optimal.

What conclusions can be reached about long-range ITS deployment planning?

These following points are a brief summary of the major conclusions of this study.

- There are many ITS strategies that have long-range deployment issues.
- Long-range ITS deployment planning can be conducted using essentially the same process as strategic ITS planning, except that staging decisions become more explicit, stakeholder input is needed at different points in the process and different methods are needed to forecast the effects of ITS elements on future traffic conditions.
- Primary difficulties in generating and evaluating ITS alternatives relate to the huge number of possible alternatives and the needs to consider prior year commitments, short-lived traffic phenomenon and random effects.
- Currently there is no software package that can adequately evaluate long-range ITS deployments.
- When using simulations to evaluate ITS alternatives, it is essential that stakeholder input be solicited prior to specifying the simulation.
- The generation of alternatives is a combinatorial optimization problem where there can be a very large number of possible alternatives. Stakeholder input is critically important as it may have a constraining effect on the number of solutions, making the optimization more tractable.
- It is recommended that both an IDAS-like model and a DTFM be used to evaluate long-range ITS deployment strategies. An IDAS-like can be used to incorporate stakeholder input into a screening process for workable alternatives. The DTFM can be used to refine and optimize those alternatives selected by the IDAS-like model.

Introduction

This report deals with the issue of how ITS (Intelligent Transportation Systems) strategies and technologies should be implemented over a long period of time (e.g., 10 to 20 years). It is common practice for long-range transportation plans to include ITS elements, but there is not a coherent body of methodologies for deciding when and how ITS strategies should be deployed in accordance with asset management or transportation planning principles.

There are four principal complicating factors when attempting to determine the timing of ITS strategies. First, the effectiveness of many ITS strategies (e.g., ramp metering and incident management) depend on the level of traffic demand. As traffic demand grows and shifts to new locations, ITS strategies that would have previously been ineffective may become effective or vice versa. Second, ITS technologies require a considerable amount of maintenance and other operational resources and are subject to obsolescence and depreciation. Thus, a premature deployment of an ITS technology could result in substantial unwarranted costs. Third, there is often a logical order to ITS strategies; some strategies should precede others. Fourth, many ITS strategies affect traffic demand, either by design or by unintended consequence and those changes in demand may affect future deployment decisions. The complexity, scope, and geographic range of certain strategies should grow according to a rational process through time.

A considerable amount of effort has already been devoted to developing methodologies for short-range ITS deployment. For example, the federal government has recently developed IDAS (ITS Deployment Analysis System), a computer program for evaluating individual and combinations of ITS strategies. Also, there are many computer programs for determining optimal ramp meter arrangements and for optimizing other specific ITS elements. However, there has not been a significant body of research that addresses the long-range ITS deployment problem.

This report addresses the following questions:

- Are there many ITS strategies that have long-range implications and, if so, which of the strategies have greatest relevance?
- What is the status of software tools for investigating the effects of ITS deployment over the long range? Can existing software tools be successfully used in long-range ITS deployment planning? How can those software tools be improved to provide better evaluations of ITS deployment plans? What are the obstacles?
- Is there a consensus as to the best way of performing strategic ITS deployment planning? What features of strategic ITS planning should be retained for long-range ITS planning?
- Can a workable methodology for long-range ITS deployment planning be demonstrated?

Deployment, Strategies and Elements

An ITS deployment consists of one or more strategies, each consisting of one or more elements. An element is most often a single implementation of a device, such as a variable message sign, a ramp meter or a pre-emptive signal. A strategy is typically a package of like elements that help accomplish a goal for the transportation system. The next section contains a list of strategies that are particularly interesting from a long-range deployment perspective.

Candidate ITS Strategies for the Long-Range Deployment Project

Eventually, this report will describe methods of accomplishing long-range deployment of ITS strategies, both procedural and analytical. Some of the methods are complicated and abstract, so it is helpful to first define the types of strategies that are subject to these methods and to then use those strategies as reference points and case studies. Given the large number of possible strategies, there is a further need to focus on a few of them that have the greatest long-range implications for the Midwest region of the United States.

The following list of strategies illustrates the need for a long-range perspective when developing ITS deployment plans. These strategies were culled from the National ITS Architecture and are described in terms of seven attributes: the type of urban environment where the strategy could be deployed; the readiness of the technology; the amount of current deployments; prerequisites for implementation; reasons why the strategy has long-range implications; and whether traffic operations models or travel forecasting models can be used for the strategy's evaluation. These attributes were assessed partially by reference to the document "What Have We Learned about Intelligent Transportation Systems?" (FHWA, 2000).

1. Integration of the network signal systems control with the controls of freeways

- Applies to any city with freeways
- Not off-the-shelf technology
- Few current deployments
- Prerequisites: would need a seriously restrictive freeway control strategy, such as ramp meters or ramp gates; needs standards for interoperability
- Long-range because: (a) future technology; (b) benefits depend on levels of congestion
- Can be partially assessed with a traffic operations model (without traffic rerouting)
- Very complex to assess through a travel forecasting model

2. Preferential treatment for transit vehicles, including diamond lanes and preemptive signalization

- Applies to any city with bus transit, on-street light-rail transit
- Off-the-shelf technology
- Limited deployments
- Prerequisites: none
- Long-range because: (a) benefits depend on level of congestion; (b) precision of existing signal timing; (b) emissions by competing modes
- Can be partially assessed with a traffic operations model (without mode split or traffic rerouting)
- Not difficult to assess with a travel forecasting model

3. Preferential treatment for HOV (high occupancy vehicles) (other than transit)

- Applies to any city with wide freeways and ramp meters
- Conventional technology
- Widespread deployment
- Prerequisites: none
- Long-range because: (a) benefits depend upon number of lanes and automobile occupancy; (b) emissions by competing modes
- Can be partially assessed with a traffic operations model (without mode split or traffic rerouting)
- Not difficult with a travel forecasting model

4. Control of traffic signalization, principally area-wide

- Applies to any city
- Off-the-shelf technology
- Limited deployment
- Prerequisites: needs extensive communications hardware
- Long-range because: (a) benefits depend upon network complexity and signal density; (b) benefits depend upon the level of congestion; (c) deployment depends upon less intense strategies having been implemented first
- Can be partially assessed with a traffic operations model (without traffic rerouting)
- Can be analyzed with a travel forecasting model, provided some good signal delay routines are included in the software

5. Control of dynamic traffic signing (including the signs)

- Applies to any city, but probably most applicable to one with freeway congestion
- Off-the-self components
- Moderate level of deployment
- Prerequisites: needs communications hardware, VMSs
- Long range because: benefits depend on having considerable congestion or relatively frequent occurrences of LOS F[1] traffic
- Cannot be assessed with a traffic operations model, as benefits relate to the ability to reroute traffic
- Can be analyzed with a travel forecasting model with assumptions about the degree of rerouting that can occur during typical situations

6. Dynamic control over the infrastructure (reversible lanes, turning restrictions, etc.)

- Applies to any city
- Some off-the-shelf components
- Limited deployment
- Prerequisites: needs extensive communications hardware

[1] LOS F is the worst category of level of service defined in the highway capacity manual. For freeways and multilane highways, LOS F implies stop-and-go conditions.

- Long-range because: (a) deployment depends upon less intense strategies having been implemented first; (b) driver acceptance may take time to develop
- May be difficult to assess with a traffic operations model, depending upon the type of sign and the accuracy of behavioral assumptions
- Difficult for a travel forecasting model to show sensitivity to some types of signs

7. Management of scheduled/planned incidents

- Applies to any city, but more so to cities with congested freeways
- Conventional technologies
- Moderate level of deployment
- Prerequisites: none
- Long-range because: benefits depend upon the level of congestion
- Cannot be analyzed with a traffic operations model because of the need to handle traffic rerouting, mode split and time-of-day issues
- Can be analyzed with a travel forecasting model, but some assumptions about the reaction of drivers would be necessary

8. Coordinated response to incidents

- Applies to any city, but more so to cities with congested freeways
- Off-the-shelf technologies
- Moderate level of deployment
- Prerequisites: must have considerable infrastructure of VMSs and other communication technologies and (perhaps) means to control entry to freeways
- Long-range because: (a) benefits depend upon the level of congestion; (b) deployment depends upon less intense strategies having been implemented first
- Can be partially assessed with a traffic operations model (without traffic rerouting)
- Can be analyzed with a travel forecasting model, but some assumptions about traffic queuing would be required

9. Roadway pricing that responds to the need for congestion or air pollution control to include: road user and toll rates, transit fares adjusted concomitant with tolls, time of day usage pricing

- Applies to any city with serious congestion problems or air quality problems that cannot be mitigated with lesser forms of traffic control
- Off-the-shelf technologies
- Very limited deployment
- Prerequisites: none, technically, but political conditions must be right (perhaps demonstrated by success of less aggressive pricing strategies)
- Long-range because: (a) benefits depend upon the level of congestion or traffic volumes; (b) users will only accept this strategy after many years of serious traffic congestion
- Cannot be analyzed with a traffic operations model
- Can be readily analyzed with a travel forecasting model

10. Management and control strategies for parking management to include price structure, allocation to selected vehicles and variable message signs

- Applies to any city with parking shortages or serious traffic congestion near activity centers with air quality problems
- Off-the-shelf technologies
- Very limited deployment
- Prerequisites: none, technically, but political conditions must be right
- Long-range because: (a) benefits depend upon parking supply constraints, which is related to the level of development; (b) benefits depend on the level of traffic near activity centers
- Cannot be analyzed with a traffic operations model
- Can be analyzed with a travel forecasting modes, but an unconventional network is required

11. Pre-trip information to assist travelers in making mode choices, travel time estimates and route decisions prior to departure

- Applies to any city
- Off-the-shelf technologies
- Limited deployment
- Prerequisites: would be facilitated with a large number of households and businesses with fast Internet connections
- Long-range because: benefits depend upon the level of congestion
- Cannot be analyzed with a traffic operations model
- Can be readily analyzed with a travel forecasting model, assuming the level of compliance with correct information

12. En route driver information that provides vehicle drivers with information, while en route, which will allow alternative routes to be chosen for their destination

- Applies to any city
- Off-the-shelf technologies
- Limited deployment
- Prerequisites: a critical mass of in-vehicle communication systems beyond car radio
- Long-range because: benefits depend upon the level of congestion
- Cannot be analyzed with a traffic operations model
- Can be readily analyzed with a travel forecasting model, assuming the level of compliance with correct information

Strategies for Further Investigation

Of the twelve strategies listed in the previous section, only a few are of particular relevance to transportation engineers in the Midwest region. The following three items provide a more focused set of strategies, as recommended by the project's advisory committee.

A. Integration of network signal systems control with the controls of freeways. This item would also include elements of the control of traffic signalization, principally area wide. (Arterial/Freeway Integration)
B. Management of scheduled/planned incidents (including traffic spikes from special events). (Scheduled/Planned Incidents)
C. Pre-trip and en route information to assist travelers in making mode choices, travel time estimates and route decisions prior to departure. This item would also include control of dynamic traffic signing (including the signs) and en route driver information that facilitates the choice of alternative routes. (Trip Information)

These particular strategies will serve as reference points for the evaluation and formulation of tools for long-range ITS deployment assessment.

Strategic ITS Planning

It is important to understand the nature of strategic ITS planning before proposing procedures for long-range ITS planning. To this end, several recent ITS planning reports were reviewed to determine the current styles and contents of such studies.

Figure 1 is an idealized ITS strategic planning procedure that was developed by taking the best parts of the many planning reports that were reviewed. None of the plans had all of the steps shown.

User Needs: The first step is to identify needs of travelers, especially the needs of drivers, transit riders and emergency personnel. This step requires the identification of all user groups and a procedure by which their needs can be ascertained, described and ranked. In many ways, the satisfaction of user needs constitutes the mission of the ITS program.

Goals: Goals are broad statements that convey the underlying rationale for the particular ITS deployment. Goals should make specific reference to the user groups defined earlier. Goals should represent well-recognized societal values. A summary statement of goals constitutes a vision statement for the deployment.

Conventional Approaches: It is important to recognize that many of the goals can be achieved by conventional approaches to providing transportation infrastructure as well as by ITS. The conventional approaches that might satisfy the goals must be identified, described and evaluated for their potential effectiveness, costs and political viability.

Objectives: Objectives are typically more detailed statements of goals, but can be measured for attainment. Objectives are often related to one or more criteria, which are usually measures of effectiveness (MOEs). Also, objectives are sometimes associated with standards that can be used to determine whether the objective has been met.

Candidate ITS Strategies: There is a long list of possible ITS strategies, many of which are inappropriate for any given locale. This step identifies those strategies that are available in the near term and have a good chance of helping meet the goals of the ITS deployment. Where necessary, individual ITS strategies may be broken into a series of "actions", which are achievable in a single project.

Selection Process: A selection process must be developed that relates the candidate ITS strategies to the attainment of the objectives. The selection process can be quite complex, sometimes involving extensive use of traffic simulation software. The process must be able to compare the advantages, disadvantages and costs of each candidate strategy.

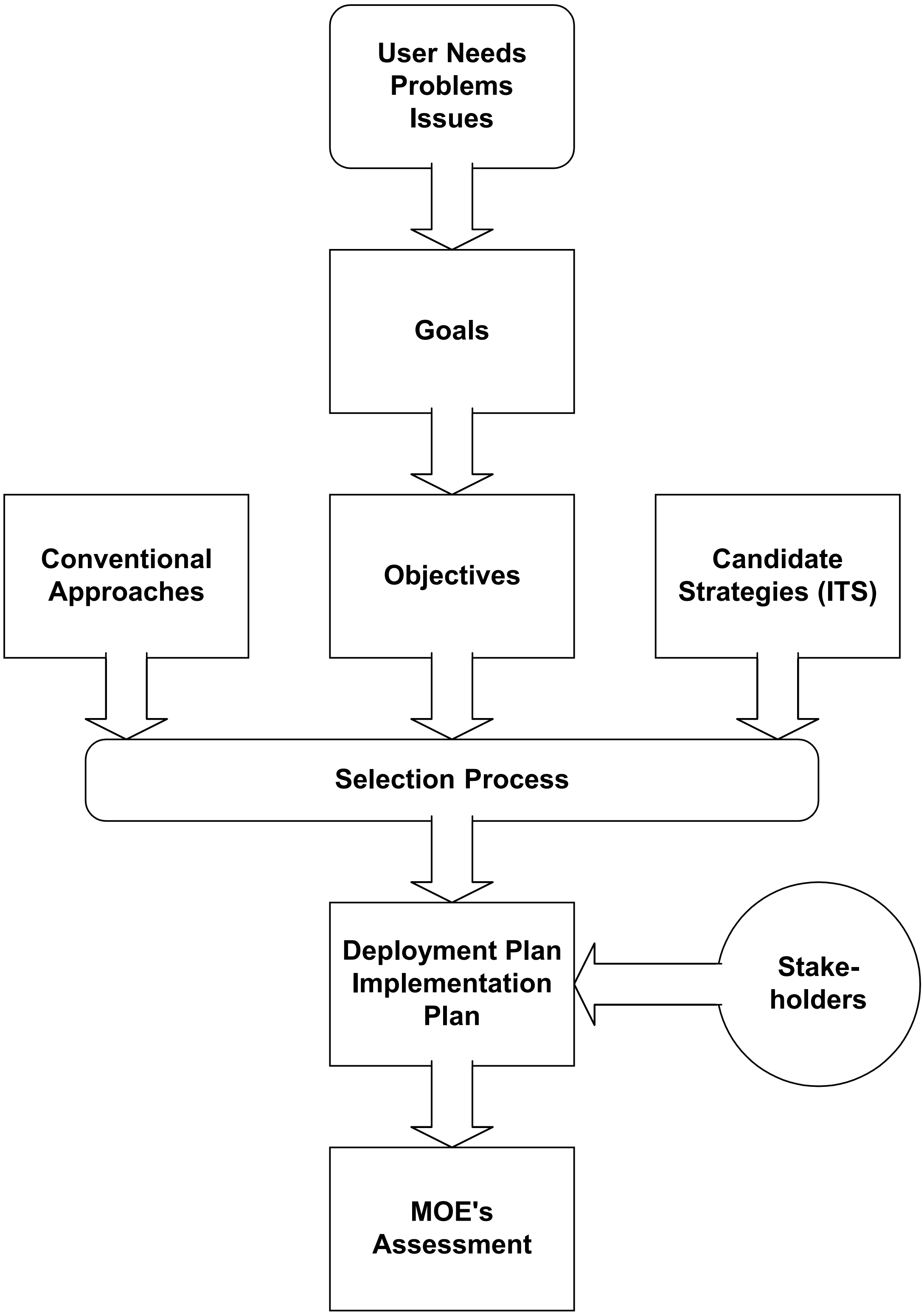
Stakeholder Input: Stakeholders are persons, agencies, organizations or companies that participate in the implementation of the ITS deployment. Stakeholders should not be confused with users, and their roles in the planning process differ considerably. Stakeholder input is required to understand the technical feasibility of the deployment, to determine if the timing of the deployment makes sense and to provide a political reality check. Stakeholder input also verifies the results of the selection process.

Deployment Plan: The deployment plan lists the ITS strategies, their locations and the timing of their implementation. Specific equipment and architecture may also be included in the deployment plan. Necessary policy changes are included. Alternatives may be proposed.

Criteria, MOEs and Assessment: The value of the plan is established by computing the values of the criteria, usually MOEs, to determine whether objectives will be met. Some agencies are comfortable with calculating monetary benefits and costs. Criteria values from different alternatives, including the null alternative and alternatives involving conventional approaches, should be compared to ascertain the best overall alternative.

The means by which many of these steps are addressed in the recent planning studies are described in the next sections.

Figure 1. Ideal Process for Strategic ITS Deployment Planning



Goals, Objectives and Vision Statements

Nearly every report we reviewed highlighted goals and objectives for its region. Vision statements were offered in roughly half of the planning reports. The reviewed vision statements were idealistic, all-encompassing assertions of what each region would like to see its ITS evolve into. Some reports included "mission" statements, which establish an identity for the agency and describe the range of actions that could be accomplished. The goals were more defined ideals that dealt with specific transportation needs, such as safety, traffic speeds and efficiency. Objectives were goal-specific statements that defined explicit steps towards achieving particular goals.

Vision Statements

Iowa DOTs ITS program outlined their vision with the following statement.

> *The vision for the state of Iowa is one of enhanced transportation, mobility, efficiency, productivity and safety through the use of user-friendly ITS technologies and systems.*

The report continues to describe how the vision "encompasses transportation problems that can be effectively addressed with the resources available in Iowa and applies to all single and multi-modal users who travel within and through the state."

The Houston – Galveston Area Council prepared a regional ITS plan (RITS) and in it proposed the following vision statement.

> *The vision of RITS is an ITS for the eight-county region effective in improving mobility for people, goods, and services; improving safety; conserving energy; and reducing environmental impact.*

The report then adds a Mission Statement:

> *The mission of RITS is to enhance transportation user services for the eight-county region by effectively and efficiently applying advanced technologies and techniques for travel and traffic management, public transportation management, traveler information systems, travel payment, commercial vehicle operations, railroad at-grade crossing controls, emergency management, and advanced vehicle safety systems.*

Thus, this mission statement sets forth a broad concept for an operating policy.

An elaborate vision statement defined the ambitions of the Colorado DOT's (CDOT) ITS Strategic Plan. The report reads:

> *The vision is one in which ITS is a significant element of CDOT's portfolio of investments providing highly cost-effective strategies for meeting Colorado's current and future transportation needs by:*
>
> - ***Improving mobility through maximizing the productivity of the transportation system*** *by using ITS to increase the throughput of passengers and vehicles on the*

transportation system. This will effectively increase the capacity of the existing transportation system. CDOT would use ITS to continuously manage and fine tune the operation of the transportation system in response to travel demand and in the event of incidents that interrupt their normal operations.

- ***Improving mobility through providing travel choices and increasing travel efficiency*** *through access to comprehensive, reliable, accurate, and timely traveler information, travelers will be able to make informed decisions concerning their travel prior to and during travel. ITS will enable travelers and businesses to choose travel time, mode, and route more efficiently based on real time information regarding travel conditions. This will help spread the volume of travelers among modes and over time, reduce the costs of doing business, and enhance the quality of life in Colorado.*
- ***Increase safety for the traveling public*** *by enabling a faster response to incidents and reducing incidents through active traffic and incident management. A secondary mobility benefit is realized from broadcasting of alternative traffic routings for avoiding incidents and resulting congestion in incident areas. These alternative routings and traffic patterns will be developed as part of Incident Management Plans. CDOT will use a combination of ITS technologies to enhance the safety of the traveling public, by monitoring system operations, planning and managing transportation affected by special events, and providing travel related weather advisory information.*
- ***Enhancing intermodal connectivity and inter-jurisdictional coordination*** *by promoting and supporting seamless intermodal transportation connectivity and Colorado's ITS systems. CDOT envisions managing information as a resource that will enhance intermodal connectivity between services provided by public and private transportation providers.*

Goals and Objectives

In existing planning studies objectives were often created to show the fulfillment of a specific goal. Goals tended to be far-reaching, while the objectives further defined a goal and described smaller steps that could be taken to achieve the goal. Many of the objectives are phased to increase or decrease a characteristic of the transportation system. Chittenden County, Virginia produced the following example of goals and objectives.

Goal: Increase Efficiency

Objectives:

1. *To minimize the cost in time and money for transporting people and goods in the region.*
2. *To relieve existing congestion and prevent future congestion.*
3. *To meet transportation needs by using existing facilities more efficiently.*
4. *To optimize the operation of the transportation system.*
5. *To reduce time lost in intermodal interchange.*
6. *To improve the ability of users and operators to perform travel planning using real-time travel information.*

7. *To reduce the costs and improve the quality of data collection for transportation system planning, use, operations, maintenance and installations.*

Goal: Enhance Mobility and Accessibility

Objectives:

1. *To improve the accessibility and availability of travel options information to users of all transportation facilities.*
2. *To reduce the variability and to simplify the use of public transportation.*
3. *To improve the predictability of travel time for all transportation modes.*

Goal: Improve Safety

Objectives:

1. *To reduce the number and severity of motor vehicles collisions and associated injuries and fatalities.*
2. *To improve the average response time of emergency services.*
3. *To improve the ability to identify, respond, remove and mitigate the effects of incidents.*
4. *To enhance personal security on all modes of transportation.*

The Chittenden County report further states that these goals and objectives provide the basis for selecting the components of ITS that are applicable to the region's transportation problems.

The San Joaquin Valley ITS Strategic Deployment Plan used a similar method for presenting its goals and objectives, but used a format that highlighted which objectives were considered a higher priority than others. A sample of these goals and objectives is shown in the table below.

Table 1. Examples of Goals and Objectives from the San Joaquin Valley ITS Strategic Deployment Plan

GOAL	OBJECTIVES
1.0 Reduce Traffic Congestion	1.1 Reduce the number and duration of accidents and incidents◆
	1.2 Minimize the congestion and delays imposed by trucks on other traffic, including those related to the differences between truck and auto speeds, and designation and compliance with truck routes.◆
	1.3 Reduce the delays at traffic signals by improving signal coordination, especially across jurisdictions◆
	1.6 Improve the management of traffic at incident scenes and in incident-related traffic diversions.■
	1.7 Minimize the congestion concerns associated with outdated roadway designs.■
	1.8 Reduce the congestion and delays associated with agricultural vehicles.
2.0 Reduce the number and severity of accidents and incidents	2.1 Reduce the number and severity of accidents and incidents due to weather conditions, between trucks and autos, involving agricultural vehicles, and involving pedestrians and bicycles.◆
	2.2 Improve monitoring and enforcement of speed limits.◆
	2.6 Minimize the safety concerns associated with outdated roadway designs. ■
	2.7 Improve coordination among emergency responders, including getting the right equipment to the incident scenes quickly.■
	2.8 Improve the ability of travelers to find help quickly in highway emergencies●

◆ An objective that reflects at least one Priority 1 problem
■ An objective that reflects at least one Priority 2 problem
● An objective that reflects at least one Priority 3 problem
Source: San Joaquin Valley ITS Strategic Deployment Plan

The presentation of goals and objectives is not always so well categorized or hierarchical. The Houston – Galveston Regional Intelligent Transportation System (RITS) Strategic Plan first lists a series of goals, then defines a number of objectives which need to be followed to successfully achieve these goals. The goals in the Houston – Galveston RITS Strategic Plan are:

- *To increase transit usage;*
- *To increase auto occupancy;*
- *To manage recurrent and non-recurrent congestion;*
- *To increase the efficiency of persons and goods movements while improving mobility; and*
- *To enhance the safety and security of travelers.*

The objectives in the Houston – Galveston RITS Strategic Plan, which emphasize new initiatives, are as follows:

- *Develop, operate, and maintain a regional, integrated transportation management systems through the Houston TransStar Center;*
- *Develop and implement communication systems to transmit transportation data and information to and from the Houston TransStar Center;*
- *Develop and operate systems for collection of real-time traffic data and for monitoring of traffic conditions in the Houston – Galveston TMA;*
- *Develop a historic data repository;*
- *Develop and implement information systems which provide accurate and relevant transportation information for all users of the transportation network (i.e., private travelers and operators of transit and commercial vehicles);*
- *Develop and operate a fully automated and integrated traffic signal system in the Houston – Galveston TMA;*
- *Provide resources for rapid detection of incidents and timely response with appropriate resources to minimize impact on traffic operations;*
- *Provide resources for swift mobilization and response during weather emergencies;*
- *Promote and encourage public-private partnerships in the development and deployment of intelligent transportation systems; and*
- *Encourage and facilitate the application of evolving ITS concepts, such as travel payment and advanced vehicle safety systems.*

Strategies

Every reviewed report outlined ITS strategies the agency was planning to undertake. There were many different strategies, and nearly as many different ways of presenting them. Several example lists of ITS strategies are presented in this section.

A simple outline of regional ITS strategies was offered in the Pima (Arizona) Association of Governments' ITS Strategic Plan.

Table 2. Time Staging of ITS Strategies from Pima Association of Governments' ITS Strategic Plan

TIME FRAME	USER SERVICE
Short Term	Pre-Trip Traveler Information
	Traffic Control
	Incident Management
	En route Travel Information
	Ride-Matching and Reservation
	Public Transportation Management
	Commercial Vehicle Electronic Clearance
Medium Term	Travel Demand Management & Operations
	Personalized Public Transit
Long Term	Route Guidance

Source: ITS Intelligent Transportation Systems Strategic Deployment Plan, Pima Association of Governments

The Maricopa (Arizona) Association of Governments updated its ITS Strategic Plan in April, 2001. Their list of proposed ITS strategies included a timeframe for deployment as shown in Table 3.

Table 3. Time Staging of ITS Strategies from Maricopa Association of Governments

SHORT-TERM 2002-2006	MID-TERM 2007-2011	LONG-TERM 2012-2021
• Pre-trip travel information • En route driver information • Traveler services information • Traffic control • Incident management • Emissions testing and mitigation • Public transportation management • Commercial fleet management • Emergency notification and personal security • Emergency vehicle management • Archived data function • Other*	• Ride matching and reservation • Travel demand and management • Highway-rail intersection • En route transit information • Hazardous material incident response	• Route guidance • Personalized public transit • Public travel security

* This category captures (1) the need to develop and facilitate ITS education and marketing efforts to public and (2) the need to increase use of automated enforcement technologies (red lights, speed, etc.)
Source: MAG ITS Strategic Plan Update, April, 2001

The MAG ITS Plan goes a several steps further with Table 4, which details agencies associated with each project, probable costs, and the user needs that each project addresses.

Table 4. MAG ITS Strategic Plan – Recommended Short-Term Projects (2002-2006)

PROGRAM AREA/PROJECT	DESCRIPTION	IMPLEMENTING AGENCY	MANAGING AND OPERATING AGENCY	OPINION OF PROBABLE COST	ASSOCIATED USER NEEDS (ID NUMBERS)
Traveler Information Systems					
Integration of a regional ATIS/ATMS System	Integrate ADOT FMS/AZTech/HCRS servers (and possibly replace TRW systems) at ADOT TOC to provide integrated traveler information/traffic management system	ADOT/MCDOT	ADOT/MCDOT	$2,500,000	6,23
AZTech Work Stations (15)	Add AZTech Work Station to up to 15 new ITS cities/agencies	AZTech/MCDOT	Local Agencies	$150,000	6,10,32
Traveler Information Systems Upgrade	Upgrade existing traveler information systems (HCRS/411-ROAD/RCRS) to accommodate new technologies, such as wireless internet and in-vehicle applications.	ADOT/Local Agencies/Private Sector	ADOT/Local Agencies/Private Sector	$1,000,000	6,8,11,20
Arterial Speed Maps	Develop maps to display speeds on arterial streets	MAG/Local Agencies	Local Agencies	$500,000	6,52
SUBTOTAL				$4,150,000	
Freeway Management System					
FMS Phase 8	Install FMS Components on US 60	ADOT	ADOT	$14,070,000	2,5,6,8,16
FMS Phse 3B	Install FMS Components on I-17	ADOT	ADOT	$10,350,000	2,5,6,8,16
FMS Phase 6B	Install FMS Components on Loop 202N and on Loop 101	ADOT	ADOT	$16,560,000	2,5,6,8,17
FMS Phase 9A	Install FMS Components on Loop 101S	ADOT	ADOT	$6,00,000	2,5,6,8,18
FMS Phase 12B	Install FMS Components on Loop 101 and SR51	ADOT	ADOT	$14,600,000	2,5,6,8,19
Freeway Service Patrol/ATMS Link	Develop and implement links to connect the freeway service patrol with the ADOT TOC traffic management system.	ADOT	ADOT	$500,000	2,5,8,10,12
ADOT TOC Upgrades	Upgrade ADOT TOC software and hardware	ADOT	ADOT	$1,000,000	2,5,6,8,21
SUBTOTAL				$63,080,000	

Source: MAG ITS Strategic Plan Update, April, 2001

Colorado's Department of Transportation based their strategies around a series of "Core Services," as shown in Table 5.

Table 5. Core Services and Strategies from the Colorado Department of Transportation

CORE SERVICES	STRATEGIES
Traffic Management	1. Establish active statewide traffic management in priority corridors.
Traveler Information	2. Continue statewide deployment of ITS devices used for collecting pre-trip and en route travel planning information. 3. Develop the Advanced Traveler Information System and use the System to disseminate statewide traveler information.
Incident Management	4. Use real-time road condition information to deploy and assist with incident response. 5. Use active traffic management capabilities to reduce congestion arising from recurring/non-recurring incidents and provide traveler information about incidents.
ITS Maintenance	6. Establish a statewide ITS maintenance planning, replacement, and budgeting process.
ITS Planning and Project Prioritization	7. Conduct statewide ITS deployment planning and provide leadership for implementing the statewide ITS enabling infrastructure. 8. Use performance measures to evaluate ITS' contributions to CDOT investment categories. 9. Institutionalize ITS into the statewide and regional planning processes. 10. Institutionalize ITS into CDOT's project scoping processes.
ITS Enabling Infrastructure	11. Deploy ITS enabling infrastructure on a statewide basis.
ITS Project Deliver Support	12. Establish statewide ITS device procurement specifications and guidelines. 13. Establish policies, procedures, and provide guidelines for inspection and acceptance of ITS components. 14. Develop and establish statewide design standards for ITS systems and devices.

Source: CDOT ITS Strategic Plan, August, 2001

CDOT's report took another step in this process by breaking down the 14 strategies into separate "actions". The strategies and their respective actions for Traffic Management and Traveler Information (the first two Core Services) are shown in Table 6, as presented in CDOT's ITS Strategic Plan.

Table 6. Actions Derived from Strategies from the Colorado Department of Transportation

Strategy 1.	**Establish active traffic management in priority corridors.**
Action 1.	Establish policies requiring the implementation of ITS devices to achieve traffic management in priority corridors.
Strategy 2.	**Continue statewide deployment of ITS devices used for collecting pre-trip and en route travel planning information**
Action 1.	Manage and coordinate deployment of systems and devices (such as CCTV, ATR's, weather information systems, probe vehicles) for collecting road condition information.
Strategy 3.	**Develop the Advanced Traveler Information System and use the System to disseminate statewide traveler information.**
Action 1.	Modify and enhance communications plans for providing traveler information to the public.
Action 3.1.	Modify and enhance communication plans for providing traveler information to the public.
Action 3.2.	Operate and further develop the role of the CDOT Web Site in disseminating traveler information.
Action 3.3.	Collect and disseminate traveler information.
Action 3.4.	Coordinate and maintain partnerships with media outlets (radio, TV, Cable TV, etc.) to disseminate traveler information.

Source: CDOT ITS Strategic Plan, August, 2001.

While most of the reviewed reports were regional ITS plans, a few were intended for specific corridors. One example is Wisconsin DOT's I-39 ITS Corridor Strategic Deployment Plan. Instead of outlining a list of proposed strategies for the corridor, the report set forth a series of recommended projects for deployment in the "Immediate Term (year 1)", "Short Term (years 2-5)", and "Medium Term (years 6-10)". Some examples from each category are listed below.

Immediate-Term Projects – Year 1

- *Communication and Integration Study*
- *Permanent Changeable Message Signs*
- *Pavement Condition Reporting System*
- *Incident Management Plan*
- *Enhanced Reference Markers*
- *Highway Advisory Radio*
- *Vehicle Surveillance and Detection: Phase 1 – Vehicle Detector Stations*

Short-Term Projects – Years 2-5

- *Traffic Operations Center / Virtual Traffic Operations Center*
- *Vehicle Surveillance and Detection: Phase 2 – CCTV Cameras*
- *Traveler Information for Commercial Radio Broadcast*
- *Web based Transit and Traveler Information*

- *Automated Vehicle Location for Emergency Fleets*

Medium-Term Projects – Years 6-10

- *Demand Responsive Transit for Rural Areas*
- *Transit Automated Vehicle Location System*
- *Signal Preemption for Emergency / Transit Fleets*

The Houston – Galveston Area Council's Regional ITS Plan outlined its strategies based on particular transportation problems in the area. Table 7 shows these problems, their respective solutions and both conventional and ITS strategies that can be implemented to address the problems.

Table 7. ITS User Services for Houston - Galveston TMA

PROBLEM	SOLUTION	CONVENTIONAL APPROACH	ITS USER SERVICES
Traffic Congestion	Increase roadway capacity (vehicular throughput)	New roads, new lanes; RR grade crossings	Advanced traffic control incident management; en route driver information; highway/rail intersection
	Increase passenger throughput	HOV lanes; carpooling; fixed route transit	En route transit information; public travel security
	Reduce demand	Flex time programs	Travel demand management
Traffic, Accidents, Injuries, and Fatalities	Improve safety	Improve roadway geometry; remove road obstacles to improve sight distance; traffic signals – protected left-hand turns at intersections; fewer at-grade crossings, railroads/streets; driver training; sobriety checkpoints; lighten dark roads; reduce speed	Emergency notification and personal security, emergency vehicle management, incident management, traffic control, en route driver information; highway/rail intersection
Lack of Mobility and Accessibility	Provide user friendly access to quality transportation services	Expand fixed route transit and paratransit services; radio and TV traffic reports	Multimodal pretrip information; en route transit information; respond dynamically to changing demand
Disconnected Transportation Modes	Improve intermodality	Static interagency agreements	Pretrip travel information; en route transit information
Transportation Following Emergencies	Improve disaster response plans	Review and improve existing emergency plans; establish emergency routing	Hazardous material incident notification; incident management; en route driver information; route guidance; emergency vehicle management
Vehicle-Based Air Pollution and Fuel Consumption	Increase transportation system efficiency, reduce travel and fuel consumption	More efficient conventional vehicles; regulations	Advanced traffic management to smooth flows; multi modal pretrip information; demand management (telecommuting, transportation pricing); emissions mitigation (alternative fuel vehicles)

Source: Houston-Galveston Area Council's RITS Strategic Plan, August, 1997.

Ranking and Prioritization of Strategies

Accompanying most lists of proposed strategies in the reviewed reports were descriptions of prioritization methods. Most were user-needs related approaches, incorporating focus group and stakeholder surveys. This section discusses several of these prioritization and ranking methods.

Iowa's Department of Transportation used a qualitative, "Strategies vs. Top Problems" process wherein ITS strategies were compared against top problems that had been identified by a stakeholder group. A score was given for each strategy based on its anticipated impact towards addressing the problem. A total score was calculated for each strategy to develop a priority order. Iowa DOT's Integrated ITS and Services Deployment Plan describes this prioritization plan in the following way.

The method used in the process of evaluating strategies was to compare the 48 potential strategies to the top 21 transportation problems in Iowa, which were identified at the May 1999 prioritization workshop. Each strategy was considered and rated based on its ability to address each of the top problems. A scaling system of 0 through 2 points was used and applied to each strategy. Two points were given to the strategy if it directly helped with the corresponding problem, while 1 point was given for a lesser indirect benefit. Zero points were awarded for no beneficial relationship between the problem and strategy.

Each strategy received a total score representing points "scored" against top problems. The highest possible score was 42. The Table 8 illustrates the results of this process for a fraction of the strategies considered.

The report continues: "Once all possible strategies were compared to the top problems, each problem was weighted based on its relative importance when ranked at the May 1999 prioritization workshop. Each individual score received by the strategies was multiplied by the weighting factor of the corresponding problem. This weighting factor was determined by the number of votes each problem received at the May workshop by the number of votes received by the top problem. This number, which ranged from 0.09 to 1.00, was then added to one. The resulting weighting factors range from 2.00 for the highest-rated problem to 1.09 for the 21st-rated problem." See Table 9 for several examples of this weighting.

As a result of the scoring and weighting, each strategy received a second total score. This score was simply a total of weighted points "scored" against the top problems. With weighting factored in, the highest possible score was 54.68.

Table 8. Ranking of ITS Strategies in Iowa

OVERALL RANK	POTENTIAL STRATEGIES	TOP PROBLEMS																					TOTAL SCORES
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
		Safety / Crashes Highway	Construction & Maint. Highways	Personal Security - Highways	Lack of Rosd Conditions Information	Construction and Maint. - Streets	Safety / Crashes - Streets	Road Surface Conditions - Highway	Personal Security - Streets	Road Surface Conditions - Streets	Railroad Crossings - Streets	EMS Response Time - Streets	Lack of Weather Conditions Info	Recurring Congestion - Streets	Travel Time - Highways	Travel Time - Streets	Lack of Rural Transit Coordination	Lack of Adequate Alternate Routes	Integration of Data	CVO Regulatory Time Spent	Lack of Multi-Modal Traveler Info.	CVO Time Spent at Weigh Stations	
	TIS Planning, Marketing, Administration																						
1	ITS Program and Data Administration	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	22
5	ITS Plans and Studies	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
5	ITS Marketing and Education Programs	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
	Travel and Traffic Management																						
5	Metro Area Traffic Management Systems	2	1	1	1	1	2	0	1	0	0	1	1	2	2	2	0	0	2	0	2	0	21
11	Smart Work Zones / Portable Traffic Management Systems	2	2	1	2	1	1	1	0	0	0	0	0	1	2	2	0	2	0	0	2	0	19
11	Metropolitan Area Incident / Event Management	2	2	1	0	2	2	0	0	0	1	2	0	2	2	2	0	0	1	0	0	0	19
13	Roadway Weather Safety / Incident Prevention Systems	2	0	1	2	0	2	0	1	0	0	0	2	2	1	2	0	0	0	0	2	0	17
14	Event Management and Routing Programs	1	0	0	1	1	1	0	0	0	0	1	0	2	2	2	1	2	0	0	1	0	15
16	Roadway Construction Coordination System	0	2	0	0	2	0	2	0	2	0	0	0	2	1	2	0	0	0	0	1	0	14
20	Crash Investigation Systems	2	0	0	0	0	2	0	0	0	0	2	0	2	2	2	0	0	0	0	0	0	12
24	Highway - Railroad Operations and Safety Systems	2	0	0	0	0	2	0	0	0	2	0	0	2	1	2	0	0	0	0	0	0	11
25	Regional Traffic Signal Coordination Programs	1	0	0	0	0	1	0	0	0	1	1	0	2	2	2	0	0	0	0	0	0	10
28	Virtual TMC and Smart Probe Surveillance	1	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	2	0	9
29	Automated Enforcement	2	0	0	0	0	2	0	0	0	2	0	0	1	0	1	0	0	0	0	0	0	8
36	Dynamic Toll Management / Electronic Toll Payment	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	6
47	Emissions Testing and Mitigation Programs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Integrated ITS and Services Deployment Plan, Iowa DOT.

Table 9a. Iowa's Weighted Scores ITS Strategies across Problems 1 to 11

OVERALL RANK	POTENTIAL STRATEGIES	TOP PROBLEMS										
		1	2	3	4	5	6	7	8	9	10	11
		Safety / Crashes Highway	Construction & Maint. Highways	Personal Security - Highways	Lack of Road Conditions Information	Construction and Maint. - Streets	Safety / Crashes - Streets	Road Surface Conditions - Highway	Personal Security - Streets	Road Surface Conditions - Streets	Railroad Crossings - Streets	EMS Response Time - Streets
	TIS Planning, Marketing, Administration											
1	ITS Program and Data Administration	2.00	1.66	1.60	1.46	1.43	1.40	1.37	1.34	1.23	1.20	1.20
5	ITS Plans and Studies	2.00	1.66	1.60	1.46	1.43	1.40	1.37	1.34	1.23	1.20	1.20
5	ITS Marketing and Education Programs	2.00	1.66	1.60	1.46	1.43	1.40	1.37	1.34	1.23	1.20	1.20
	Travel and Traffic Management											
5	Metro Area Traffic Management Systems	4.00	1.66	1.60	1.46	1.43	2.80	0.00	1.34	0.00	0.00	1.20
11	Smart Work Zones / Portable Traffic Management Systems	4.00	3.32	1.60	0.00	2.86	2.80	0.00	0.00	0.00	1.20	2.40
11	Metropolitan Area Incident / Event Management	4.00	3.32	1.60	2.92	1.43	1.40	1.37	0.00	0.00	0.00	0.00
13	Roadway Weather Safety / Incident Prevention Systems	4.00	0.00	1.60	2.92	0.00	2.80	0.00	1.34	0.00	0.00	0.00
14	Event Management and Routing Programs	2.00	0.00	0.00	1.46	1.43	1.40	0.00	0.00	0.00	0.00	1.20
16	Roadway Construction Coordination System	0.00	3.32	0.00	0.00	2.86	0.00	2.74	0.00	2.46	0.00	0.00
20	Crash Investigation Systems	4.00	0.00	0.00	0.00	0.00	2.80	0.00	0.00	0.00	0.00	2.40
24	Highway - Railroad Operations and Safety Systems	4.00	0.00	0.00	0.00	0.00	2.80	0.00	0.00	0.00	2.40	0.00
25	Regional Traffic Signal Coordination Programs	2.00	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	1.20	1.20
28	Virtual TMC and Smart Probe Surveillance	4.00	0.00	0.00	0.00	0.00	2.80	0.00	0.00	0.00	2.40	0.00
29	Automated Enforcement	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36	Dynamic Toll Management / Electronic Toll Payment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
47	Emissions Testing and Mitigation Programs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: Integrated ITS and Services Deployment Plan, Iowa DOT.

Table 9b. Iowa's Weighted Scores ITS Strategies across Problems 12 to 21

OVERALL RANK	POTENTIAL STRATEGIES	TOP PROBLEMS										TOTAL SCORES
		12	13	14	15	16	17	18	19	20	21	
		Lack of Weather Conditions Info	Recurring Congestion - Streets	Travel Time - Highways	Travel Time - Streets	Lack of Rural Transit Coordination	Lack of Adequate Alternate Routes	Integration of Data	CVO Regulatory Time Spent	Lack of Multi-Modal Traveler Info.	CVO Time Spent at Weigh Stations	
	ITS Planning, Marketing, Administration											
1	ITS Program and Data Administration	1.20	1.20	1.20	1.17	1.17	1.11	2.22	1.11	1.09	1.09	28.45
5	ITS Plans and Studies	1.20	1.20	1.20	1.17	1.17	1.11	1.11	1.11	1.09	1.09	27.34
5	ITS Marketing and Education Programs	1.20	1.20	1.20	1.17	1.17	1.11	1.11	1.11	1.09	1.09	27.34
	Travel and Traffic Management											
5	Metro Area Traffic Management Systems	1.20	2.40	2.40	2.34	0.00	0.00	2.22	0.00	2.18	0.00	28.23
11	Smart Work Zones / Portable Traffic Management Systems	0.00	2.40	2.40	2.34	0.00	0.00	1.11	0.00	0.00	0.00	26.43
11	Metropolitan Area Incident / Event Management	0.00	1.20	2.40	2.34	0.00	2.22	0.00	0.00	2.18	0.00	26.38
13	Roadway Weather Safety / Incident Prevention Systems	2.40	2.40	1.20	2.34	0.00	0.00	0.00	0.00	2.18	0.00	23.18
14	Event Management and Routing Programs	0.00	2.40	2.40	2.34	1.17	2.22	0.00	0.00	1.09	0.00	19.11
16	Roadway Construction Coordination System	0.00	2.40	1.20	2.34	0.00	0.00	0.00	0.00	1.09	0.00	18.41
20	Crash Investigation Systems	0.00	2.40	2.40	2.34	0.00	0.00	0.00	0.00	0.00	0.00	16.34
24	Highway - Railroad Operations and Safety Systems	0.00	2.40	1.20	2.34	0.00	0.00	0.00	0.00	0.00	0.00	15.14
25	Regional Traffic Signal Coordination Programs	0.00	2.40	2.40	2.34	0.00	0.00	0.00	0.00	0.00	0.00	12.94
28	Virtual TMC and Smart Probe Surveillance	0.00	1.20	0.00	1.17	0.00	0.00	0.00	0.00	0.00	0.00	11.57
29	Automated Enforcement	0.00	2.40	2.40	2.34	0.00	0.00	0.00	0.00	2.18	0.00	11.32
36	Dynamic Toll Management / Electronic Toll Payment	0.00	2.40	2.40	2.34	0.00	0.00	0.00	0.00	0.00	0.00	7.14
47	Emissions Testing and Mitigation Programs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: Integrated ITS and Services Deployment Plan, Iowa DOT.

The Wisconsin Department of Transportation (WisDOT) has developed a similar approach for prioritizing ITS projects in southwestern Wisconsin. In the report "A Methodology for Prioritizing ITS Projects in Southwestern Wisconsin," WisDOT outlines four primary steps.

1. Select System Performance Criteria
2. Rate the Impact of Each Potential Project
3. Rank the Importance of System Performance Criteria
4. Rank the Projects

The steps are broken down and described as follows:

Step 1. Select System Performance Criteria
In this step, the system performance criteria that are to be addressed should be clearly defined and selected. The system performance criteria that are selected should related to the five National ITS Program goal areas, which include:

- *Safety*
- *Mobility*
- *Efficiency*
- *Productivity*
- *Energy and Efficiency*

Specific performance criteria consistent with the key measures of effectiveness (MOEs) identified by the ITS Evaluation Resource Guide should be selected, as well as additional criteria based on opinions from a wide-ranging group of transportation system stakeholders, including:

- *Law Enforcement*
- *Emergency Response*
- *Public Safety*
- *Transportation Management and Operations*
- *Maintenance*

Step 2. Rate the Impact of Each Potential Project
In this step, the impact of each potential project on the previously defined system performance criteria should be estimated. The impacts of each of the solutions should be estimated either by a group of stakeholders similar to the group that defined the system performance criteria, or by documented evaluations into the impacts of each solution in previous projects. The scoring system used to estimate these impacts should be kept simple and the scale of rankings kept small to make it as objective as possible. Using only three potential scores, such as zero through two will prevent the scoring from being overly subjective. A score of two points applies to a project if it directly helps with the corresponding system performance criteria while one point applies to a lesser, indirect benefit. Zero points applies if there is no beneficial relationship between the system performance criteria and project.

Step 3. Rank the Importance of System Performance Criteria

In this step, the relative importance should be determined for each of the defined system performance criteria. Stakeholder opinions should be polled. Specifically, all of the stakeholders should be asked to identify which system performance criteria they consider most critical to their agencies. This can be accomplished by using a ranking scale of one to three, where one corresponds to a system performance criteria that is not important, two corresponds to a system performance criteria that is moderately important, and three corresponds to a system performance criteria that is very important. The criteria that have higher scores of importance are given a higher rank factor. Specifically, the ranking factors should be developed by calculating the average response for each criterion.

Step 4. Rank the Projects
The impact scores for each project (Step 2) are multiplied by the rank factor for each performance step (Step 3). A subtotal average is then calculated for each National ITS Program goal area. This equalizes each goal area, and avoids emphasizing a goal area with many performance criteria over a goal with few performance criteria. The potential projects were then prioritized by the total of the averages*, which is the total of the subtotal averages for each of the National ITS Program goal areas. The potential projects are then prioritized based on these ranked results.*

The Houston – Galveston Area's Regional ITS Strategic Plan identified an assessment of technologies and institutional responsibilities that accompany each strategy on their list of deployment priorities. The report reads:

The technology considerations included the categories of surveillance and sensors, location identification, communications, algorithms, and control. The National ITS Architecture document entitled Implementation Strategy *contains a more detailed summarization of these. The technologies are classified a mature, emerging, or immature. Some user services received a low ranking for area-wide deployment, even though they are important to the region. For instance, the user services "emissions testing and mitigation" received a low ranking because enforcement applications technologies that monitor emissions for specific vehicles are not yet mature and because existing enforcement of individual vehicle emissions is currently done on a statewide basis.*

Table 10 illustrates the ranking and technologies assessment of the Houston – Galveston area's ITS Strategies.

Table 10. Houston - Galveston Area Assessment of ITS User Services And Prioritization

USER SERVICES	TECHNOLOGY					INSTITUTIONAL RESPONSIBILITY				RANKING
	Surveillance and sensor	Location ID	Communications	Algorithms	Control	Primarily regional	Primarily a statewide	Primarily a federal	Primarily a private	
Incident Management	M	M	M	E		X				High
Traffic Control	M		M	E	M	X				High
Pretrip Travel Information	M	M	M	E		X				High
Public Transportation Managment		M	M			X				High
En Route Transit Information		M	M	E		X				High
Travel Demand Management		M	M	E	M	X				High
Public Travel Security		M	M			X				High
Hazardous Material Incident Response		M	M	E		X				High
Emergency Vehicle Management	M	M	M	E		X				High
Highway - Rail Intersection	M	M	M	E	M	X				High
Emergency Notification and Personal Security		M	M			X				Medium
En Route Driver Information	M	M	M	E		X			X	Medium
Electronic Payment Services		M	M	E		X			X	Medium
On-Board Safety Monitoring	M			E					X	Medium
Ride Matching and Reservation	M		M			X				Medium
Route Guidance	M	M	M	E					X	Low
Traveler Services Information	M	M	M	E					X	Low
Emissions Testing and Mitigation	E		M	E			X			Low
Personalized Public Transit		M	M			X				Low
Automated Vehicle Operation	E	M	M	E	M			X		Low
Longitudinal Collison Avoidance	I			E					X	Low
Lateral Collision Avoidance	I			E					X	Low
Intersection Collision Avoidance	I		M	E	M	X				Low
Commercial Fleet Management		M	M	E					X	Low
Commercial Vehicle Administration Processes					M			X		Low
Automated Roadside Safety Inspection	M		M	E	M		X			Low
Commercial Vehicle Electronic Clearance					M		X			Low
Vision Enhancement for Crash Avoidance	I								X	Low
Safety Readiness	E			E		X				Low
Precrash Restraint Deployment	I			E					X	Low

Key: M = mature; E = emerging; I = immature
Source: Source: HGAC RITS Strategic Plan.

Dane County, Wisconsin prepared an Incident Management Program using an effective method of setting up a prioritization for their strategies. A worksheet was sent to a series of stakeholders and each was asked to rank 10 performance criteria from which they thought was the most important to that which they considered least important. The stakeholders' rankings were tallied from their worksheets and the result was a table that outlined ranked strategies for the county to work with. A copy of the worksheet (Figure 2) and a table of results (Table 11) are shown below.

Figure 2. Prioritization Worksheet for Dane County (Wisconsin)

Prioritization Worksheet

Instructions: Please rank the following ten Performance Criteria from 10 to 1 in priority order, such that 10 is the most important, 9 is the second most important, 8 next, and so on with a rank of 1 being the least important. Please do not duplicate any numbers. After completing the worksheet, please fax to Steve Cyra, HNTB at (608) 259-0084.

________ A. Increase Transportation Efficiency
- Increase Person Miles Traveled per Lane Mile
- Reduce Control Delay

________ B. Reduce Incident Related Congestion
- Reduce Delays
- Reduce Travel Times

________ C. Enhance / Facilitate Incident Management
- Improve Detection Time
- Improve Response Time

________ D. Improve Safety of Emergency Personnel at Incident Site
- Reduce Volumes, Speeds at Incident Sites
- Reduce Secondary Crashes at Incident Sites

________ E. Increase Safety
- Reduce Accident Rate
- Reduce Fatality Rate

________ F. Facilitate Compliance With Clean Air Mandates
- Reduce Vehicle Emissions
- Reduce Fuel Consumption

________ G. Enhance Agency Activities
- Increase Interagency Activities
- Improve Resource Utilization

________ H. Integrate Transportation Services
- Increase Number of Transportation Alternatives
- Increase Number of Coordinating Agencies

________ I. Improve User Convenience
- Qualitative Assessment of User Convenience

________ J. Enhance Communications with Public
- Enhance Public Perceptions

Table 11. Performance Criteria Prioritization Results for Dane County (Wisconsin)

PERFORMANCE CRITERIA	AVERAGE RATING
Increase Safety	8.9
Reduce Incident Related Congestion	8.1
Enhance / Facilitate Incident Management	7.5
Increase Transportation Efficiency	7.1
Improve Safety of Emergency Personnel at Incident Site	6.3
Enhance Communication with Public	4.9
Improve User Convenience	3.8
Enhance Agency Activities	3.7
Integrate Transportation Services	2.9
Facilitate Compliance with Clean Air Mandates	1.9

Source: Strategic Deployment Plan, Dane County Incident Management Program.

MOE's and Performance Measures

Many of the reports we reviewed outlined a number of performance measures or measures of effectiveness. MOE's are strategy-specific outcomes by which the success or shortcoming of a particular ITS strategy could be measured. The reports varied from being rather general in their descriptions of performance measures to being quite detailed and specific. In Wisconsin DOT's "I-39 ITS Corridor Strategic Deployment Plan" (2000), the performance criteria were separated into Quantitative Criteria and Qualitative Criteria.

Quantitative Criteria

Incidents / Safety

- *Number of incidents (by type, i.e., work zone, fatality, etc.)*
- *Incident related delay (by type, i.e., work zone, fatality, etc.)*
- *Incident response time*

Congestion / Capacity

- *Interstate and arterial flows*
- *Interstate and arterial speeds*
- *Interstate and arterial travel times*
- *Vehicle hours of travel*

Travel Time Information

- *Number of diverted trips*
- *Travel time impacts of trip diversions*
- *Traffic Peaking (Peak Hour Factors)*

Qualitative Criteria

Interagency / Interjurisdictional Cooperation

- *Incident response*
- *Construction / maintenance*
- *Signal coordination*

Public Perception

- *Convenience*
- *Effectiveness*
- *Willingness to use*
- *Privacy*

The Maricopa Association of Governments (MAG) identified evaluation measures for its 2001 ITS Strategic Plan Update. Table 12 illustrates some typical measures that "are used to evaluate projects being considered for deployment in the MAG region." On this table, the primary impacts (shown with a dot ●) represent the measures that are most typically evaluated for these types of projects. The secondary impacts (shown with a circle ○) indicate those impacts which might be significant, but are not typically considered the principal metrics for evaluating these types of ITS projects."

Table 12. Relationship between ITS Strategies and Measures of Effectiveness (MAG)

ITS STRATEGY	Accident Rate	# of Fatality Accidents	# of Injury Accidents	Response time of Incidents	Recurring Delay	Travel Time Variability	Customer Satisfaction	Facility Throughput	Cost Savings	Emission Levels	Energy Consumption
Arterial Management Systems											
Actuated Corridor Signal Coordination	●	○	○		○	●	○	●		○	○
Central Control Signal Coordination	●	○	○		○	●	○	●		○	○
Emergency Vehicle Signal Priority		○	○	●							
Transit Vehicle Signal Priority					●	●		○		○	○
Arterial Highway Advisory Radio						●		○			
Arterial Variable Message Sign						●		○			
Freeway Management Systems											
Pre-set Ramp Metering	●				●	○		○		○	○
Traffic Actuated Ramp Metering	●				○	●		○		○	○
Central Control Ramp Metering	●				○	●		○		○	○
Highway Advisory Radio						●	●	○			
Variable Message Sign						●	●	○			
Advanced Public Transit Systems											
Fixed Route – Automated Scheduling System					○	●	●				
Fixed Route – Automatic Vehicle Location					○	●	●				
Fixed Route – Security System	○	○	○				●				
Paratransit – Automated Scheduling System					○	●	●				
Paratransit – Automatic Vehicle Location					○	●	●				
Electronic Transit Fare Payment							●				
Incidence Management Systems											
Incident Detection/Verification	○	●	○			●	○	○		○	○
Incident Response/Management	○	●	○			●	○	○		○	○
Emergency Management Services											
Emergency Vehicle Control Service		●							○		
Emergency Vehicle Automatic Vehicle Location		●							○		
Regional Travel Information Systems											
Telephone-Based Traveler Information System						●	●				
Web/Internet-Based Traveler Information System						●	●				
Kiosk-Based Traveler Information System						●	●				
Commercial Vehicle Operations											
Weigh-in-Motion							●	●	○		
Safety Information Exchange	●						●	●	●		
Additional Deployments											
Traffic Management Center	○							●	●	○	○
Traffic Surveillance - CCTV		○						○	○		
Traffic Surveillance – Loop Detectors								○	○		
Parking Management Systems							○	●			
Railroad Crossing Monitoring System	●										

Source: MAG ITS Strategic Plan Update.

The Houston – Galveston Area Council used Table 13 to illustrate their performance measures as they related to particular transportation problems.

Table 13. ITS User Services and Performance Measures for Houston – Galveston TMA

PROBLEM	SOLUTION	ITS USER SERVICES	PERFORMANCE MEASURES
Traffic Congestion	Increase roadway capacity (vehicular throughput)	Advanced traffic control Incident Management En route driver information Highway-rail intersection	General Performance Measures Capacity/Demand Ratios Incident Response Times Frequency of Stops Exhaust Emissions
	Increase passenger throughput	En route transit information Public travel security	General Performance Measures Vehicle Occupancies
	Reduce Demand	Travel demand management	General Performance Measures Capacity/Demand Ratios Vehicle Occupancies Toll Collections
Traffic, Accidents, Injuries, and Fatalities	Improve Safety	Emergency notification and personal security Emergency vehicle management Incident management Traffic Control En route driver information Highway-rail intersection	Incident Response Time Accident frequency Volumes/Accident Rates
Lack of Mobility and Accessibility	Provide user friendly access to quality transportation services	Multimodal pretrip travel information En route transit information Respond dynamically to changing demand (public transportation management)	Passenger Volumes Vehicle Occupancy Modal Choice Transit Costs
Disconnected Transportation Modes	Improve intermodality	Pretrip travel information En route transit information	Passenger Volumes Vehicle Occupancy Modal Choice Transit Costs
Transportation Following Emergencies	Improve disaster response plans	Hazardous material incident notification Incident management En route driver information Route guidance Emergency vehicle mgmt.	Incident Response Time Incident Clearance Time Travel Times / Delays
Vehicle-Based Air Pollution and Fuel Consumption	Increase transportation system efficiency, reduce travel and fuel consumption	Advanced traffic management to smooth flows Multimodal pretrip information Demand Management • Telecommuting • Transportation pricing Emissions Mitigation - Alternative Fuel Vehicles	General Performance Measures Vehicle Volumes / Occupancies Fuel Consumption Number of Alternative Fuel Vehicles

Source: HGAC RITS Strategic Plan.

Wisconsin's IH 90/94 Intercity Corridor ITS Plan divided its performance measurements up by each program area and project within the plan. For each ITS project, the report outlines the following performance criteria:

- Measures of performance criteria
- Data and information requirements for application of the measure
- Data and information sources for application of the measure

Included on Table 14 are two examples of the performance measures for particular projects in the IH 90/94 ITS Plan.

Table 14a. Performance Criteria: Program Area 1: Commercial Vehicle Operations -- Project 1.2: Automated Safety Inspections/ Weigh in Motion Scales -- Subpart 2: Expansion of Ramp Weigh in Motion Scales

CATEGORY OF MEASURES	PERFORMANCE MEASURE	DATA / INFORMATION NEEDS	DATA / INFORMATION SOURCE
Technical	1. Data on system performance / operations 2. Regional interoperability 3. Database records	• Message send time • Message content • Number of retries • Information presented to user • Message receipt time • Received messages content • Vehicle weight (static scale) • Vehicle weight (WIM) • Observed vehicle data (Axles, class, height, etc) • WIM / AVC data • System reliability, accuracy, availability, durability, maintainability, etc. • Technical inventory of WisDOT CVO systems • Technical inventory of regional systems • Safety / inspection, weight, permits, fuel tax	• Test runs w/ automated and manual data logging • Log kept by operators during system operations • WisDOT project records • Agency project records • Database system
Operational	1. Annual number of vehicles processed 2. Weigh station delay 3. Number of accidents related to weigh stations	• Pre-average number of vehicles (last 5 yrs.) • Post-number of vehicles (1st Year) • Pre-average amount of delay (last 5 yrs.) • Post-average amount of delay (1st Year) • Pre-average number of accidents (last 5 yrs.) • Post-average number of accidents (1st Year)	• Weigh station records/logs • Trucking firm records/logs • Pre-/Post- delay study
Financial	1. Annual operating costs 2. Annual maintenance	• Pre-average operating costs (last 5 yrs.) • Post-operating cost (1st	• WisDOT financial records • Project financial

	costs 3. Project start-up costs	Year) • Pre-average maintenance cost (last 5 yrs.) • Post-average maintenance cost (1st year) • Project cost (design, development, deployment)	records
Human Factors	1. User perception of the system	• System utility, usefulness • Location of system in vehicle • Types of features offered • Message content • Method of delivery • Perceived weigh station delay • Comfort level w/ system • Desired additional features • Willingness-to-pay for system • Perceived benefits of system • Appropriateness of displayed information • Additional uses of system	• User survey (truckers & weigh station operators) • Interviews (truckers & weigh station operators) • "On-hands" use of system
Institutional	1. Legal impediments to deployment 2. Organizational impediments to deployment	• On-the-books laws, regulations, standards, etc. • WisDOT intra-agency divisions • Inter-agency roadblocks	• State law records • WisDOT interviews • Agency interviews

Source: 90/94 ITS Intercity Corridor Study, Strategic Deployment Plan.

Table 14b. Performance Criteria: Program Area 4: Regional Multi-Modal Information -- Project 4.1: Provide Pre-Trip Traveler Information -- Subpart 2: Expand Home Page Information on the Internet

CATEGORY OF MEASURE	PERFORMANCE MEASURE	DATA / INFORMATION NEEDS	DATA / INFORMATION SOURCE
Technical	1. Data on system performance / operations	• Type of information provided via Internet • Frequency of Internet information updates • Number/Type of information desired by travelers • Type of information desired by traveler • Number/Type of Internet screens • Message content (per Internet screen) • Internet information accuracy, reliability, timeliness, maintainability, etc. • Time to access Internet screen(s)	• Internet logs/records (automated & manual) • WisDOT project records/logs • Trial call-ins (w/ automated and manual logs)
Operational	1. Number of internet "hits"/ transactions	• Total number of hits (daily, weekly, monthly) • Average number of hits (daily, weekly, monthly) • Average time per hit • Number/Type of manual processes • Number/Type of automated processes	• WisDOT record/logs • Internet logs/records (automated & manual) • Internet Home Page system design
Financial	1. Annual operating costs 2. Annual maintenance costs 3. Project sign-up costs	• Pre-corridor study cost (last 5 yrs.) • Post-corridor study cost (1st year) • Pre-corridor study cost (last 5 yrs.) • post-corridor study cost (1st year) • Project cost (design, development, deployment)	• WisDOT financial records • Internet project financial records

Human Factors	1. User perception of internet home page	• Internet utility/usefulness • Types of information provided • Perceived time to receive Internet information • Comfort level w/Internet • Desired additional features • Perceived benefits of Internet Home Page • Additional uses of Internet • Perceived improvements in traveler information dissemination • Utility of PR Campaign • Perceived Internet ease-of-access • Perceived utility of Internet screen (content, accuracy, reliability, timeliness, maintainability, level-of-detail, etc.)	• User Survey (Internet developers / operators, motorists/callers, etc.) • Interviews (Internet developers / operators, motorists/callers, etc) • "On-hands" use of Internet Home Page/screens
Institutional	3. Legal impediments to deployment 4. Organizational impediments to deployment	• "On-the-books" laws, regulations, standards, etc. • Intra-agency divisions • Inter-agency roadblocks • Public sector issues • Private sector issues • Coordinating Internet data sources / inputs	• State law records • Public sector agency interviews • Private sector firm interviews

Source: 90/94 ITS Intercity Corridor Study, Strategic Deployment Plan.

Software Tools for Evaluating ITS Performance over a Long Range

A long-range ITS deployment of any significance requires software that simulates its traffic impact. A traffic simulation provides the values for the measures of effectiveness on which an alternative is ranked and allows an alternative to be refined by varying the strategies contained within it or by modifying the strategies themselves. Thus, a good tool for traffic simulation is an essential part of a good ITS deployment planning process. A consensus does not now exist as to how traffic should be simulated for long-range ITS deployment.

There are eight possible approaches to simulating the long-range effects of ITS.

- *Traffic Microsimulation.* Traffic microsimulation models are Monte Carlo simulations that represent the behavior of every driver using rules and random processes. This class of models can simulate a wide variety of traffic situations by adding rules for specific traffic control devices or by modifying driver behavioral characteristics. Typically these software packages do not contain demand-forecasting capabilities and traffic assignment is not equilibrium[1]. It is very time consuming to run large networks, and the models require very extensive network detail. (Examples: CORSIM, Paramics)
- *Mesoscopic Traffic Simulation with Dynamic Traffic Assignment.* This class of models is fundamentally based around dynamic traffic assignment (DTA)[2] algorithms with some short-term travel forecasting capabilities. Delay is computed by observing the behavior of groups of drivers, rather than individual drivers. This class of models is being developed by the FHWA under its TrEPS project specifically for short-term travel forecasting models for ATMS (advanced traffic management systems). Planning versions of TrEPS software is also available. (Examples: Dynasmart-P, DynaMIT-P)
- *Macroscopic Traffic Simulation.* Macroscopic models simulate or optimize traffic flow by using empirical or theoretical equations of movements of platoons of vehicles. Typically these models do not contain travel demand forecasting capabilities or traffic assignment, but work from traffic counts. These models often contain routines for setting existing traffic controls to optimize traffic flow. (Examples: TRANSYT7-F, Syncro)
- *Traditional Four-Step Travel Forecasting with Static Traffic Assignment.* These are macroscopic models containing the four-steps of trip generation[3], trip distribution[4], mode split[5] and traffic assignment. Assignment is equilibrium, but static. Delay is calculated

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[1] Equilibrium traffic assignment is a widely accepted method of simulating the amount of traffic on highways. Different methods exist for achieving an equilibrium assignment, but all methods for "user-optimal" equilibrium traffic assignment have three properties: (1) volumes on links (street segments) are consistent with travel times on the same links; (2) travel times on links are consistent with volumes on the same links; (3) and all vehicles are assigned to a shortest path through the network.

[2] Dynamic traffic assignment differs from traditional static traffic assignment by allowing links (street segments) to be loaded in small time slices. The loadings take into consideration the length of time it takes for a trip to reach a particular link.

[3] Trip generations is a step in a travel forecasting model that estimates total numbers of trips (coming and going) for each traffic analysis zone.

[4] Trip distribution is a step in a travel forecasting model that estimates where trips both start and end.

[5] Mode split is a step in a travel forecasting model that estimates the numbers of trips using each available mode between each pair of origins and destinations.

with simplistic relationships between volume and capacity, such as the BPR curve[1]. Traffic controls are crudely represented, if at all. (Examples: EMME/2, TransCAD)

- *Travel Demand Microsimulation.* There exists only one model of this class, which is similar to traffic microsimulation, except that the travel demand characteristics are also simulated using Monte Carlo techniques for every individual in the population. The concept is still under development by FHWA and cannot be fully evaluated. It is extremely time consuming to run large networks, and models require very extensive network and population detail. Because of its planning orientation, such models do not contain a very wide variety of traffic control devices. Assignment is not equilibrium, but is inherently very dynamic by using small time slices. (Example: Transims)
- *Hybrid of Four-Step with Traffic Microsimulation.* This concept uses two separate models, one to forecast demand and a second to forecast traffic impacts. The most logical configuration is a four-step travel forecasting model coupled with a traffic microsimulation model, thereby gaining the best features of both. Feedback between the models is very cumbersome and time consuming. Because of the difficultly of feedback, assignments are only partially equilibrium. (Examples: Prueviin; many home-brew combinations of models)
- *Four-Step with Integrated Macroscopic Traffic Simulation.* This class of models is similar to a traditional four-step model, but delays are calculated using operational analysis procedures from the Highway Capacity Manual or similar sources. This type of model requires extensive detail on the nature of traffic control devices and lane geometry. Assignments are static equilibrium. (Example: QRS II)
- *Specialized Static Traffic Assignment for ITS Evaluation.* The only representative of this class is a static equilibrium traffic assignment algorithm that requires demand results from a four-step model. This type of model contains capacity adjustments to account for a variety of ITS strategies. The model does not contain explicit traffic control devices for delay calculations or assignments. (Example: IDAS)

All of these tools have a role in strategic ITS evaluation, although the requirements of long-range evaluation may exceed the capabilities of all of them.

The software tools can be roughly placed on four dimensions: ability to simulate traffic operations, ability to forecast demand at some future time, ability to handle a wide range of ITS strategies (robustness) and ability to deal with accumulated effects of many ITS strategies over a long period of time (staging). Figures 3 and 4 subjectively place each software tool on these four dimensions.

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[1] The BPR curve was originally developed in the 1950's in the Bureau of Public Roads for estimating the amount of travel time along a link (street segment) associated with an amount of assigned volume. The BPR curve is simplistic and empirical; travel time is a function of only free travel time, capacity, the assigned volume and two calibrated parameters.

Figure 3. Traffic and Demand Dimensions of Software Tools for Strategic Evaluation of ITS Deployment

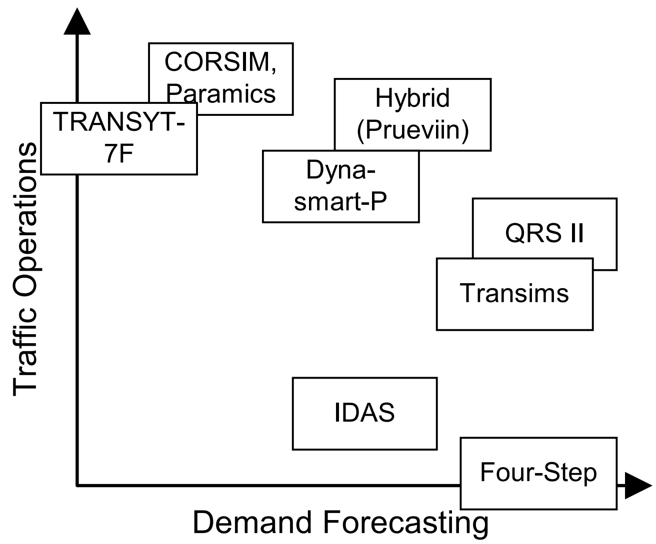
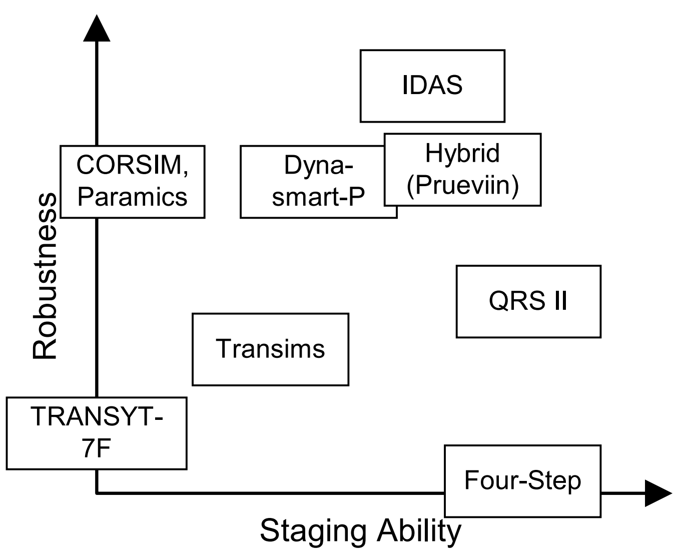


Figure 4. Robustness and Staging Dimensions of Software Tools for Strategic Evaluation of ITS Deployment



Software tools found near the upper right of both figures would appear to have the greatest potential for application in developing long-range ITS deployment strategies. This following section goes into greater depth on IDAS, Dynasmart-P, Paramics and QRS II as examples of tools within their respective classes. An example of a hybrid model is not evaluated because of the cost and difficulty of building one.

Evaluation of Specific Examples of Software Tools for Their Potential in Developing Long-Range ITS Deployment Strategies

A discussion of exact capabilities of each class of software package is difficult without reference to specific examples from each class. Knowing the capabilities of specific software packages, their strengths and their weaknesses allows development of the specifications for the best configuration (given existing technology) of a traffic simulation model. In addition, the review of specific software packages reveals deficiencies that are common to all of them.

This section provides specific reviews of four software packages (IDAS, Dynasmart-P, QRS II and Paramics) that are each an exemplary tool within the eight classes listed in the previous section. The software packages are reviewed for the applicability and adaptability for the assessment of long-range ITS deployment and are not necessarily reviewed for their intended purposes. The reviews were based on applications of the software on test networks and descriptions of features and algorithms found in software documentation and research reports. It is recognized that other software packages in their respective classes might provide greater or lesser capabilities; this section is not intended to be a review of the full range of capabilities that may exist within a class.

The four classes of models not reviewed are: macroscopic traffic simulation; hybrid of four-step with traffic microsimulation; traditional four-step travel forecasting with static traffic assignment; and travel demand microsimulation. These classes are considered to offer similar or inferior capabilities to the reviewed software packages or to have been unproven in real-world applications.

Specialized Static Traffic Assignment for ITS Evaluation: IDAS

IDAS is an example of a specialized static traffic assignment for ITS evaluation. IDAS was developed by a consultant under contract with the Federal Highway Administration and is a unique product in its class.

What is IDAS?

The ITS Deployment Analysis System (IDAS) is a software package that allows assessment of benefits and costs for many different ITS strategies that may be implemented on a traffic network. IDAS essentially consists of five major functional components: (1) a static, user-optimal equilibrium traffic assignment[1] algorithm; (2) a demand module that includes mode split; (3) an extensive library of impacts that could occur to the network or to MOEs (measures of effectiveness) when an ITS strategy is implemented, (4) an MOE calculator; and (5) a cost calculator. IDAS also has a well-designed graphical user interface (GUI) that permits easy selection of ITS strategies, locating the ITS strategies on the network and modifying parameters and assumptions. IDAS does not have trip generation or trip distribution procedures or a

[1] "User optimal" traffic assignments differ from "system optimal" traffic assignment by simulating the independent and simultaneous route selection decisions of many drivers. System optimal traffic assignments attempt to find the lowest cost routing across all drivers.

network editor. Network data and demand estimates (in the form of a trip table) must be obtained from travel forecasting software in relatively simple text formats.

How does IDAS work?

The IDAS software relates impacts and equipment. Potential impacts are documented in IDAS's ITS library, which describes the implementation of many ITS deployments from around the world.

Once a project is defined, IDAS allows different alternatives and options to be created by the user. Each project can have many different alternatives, and each alternative can have many different ITS options. Alternatives differ, at least, in their demand and network characteristics as fed to it by a travel forecasting model. Within an alternative, the particular ITS characteristics define an option. Thus, comparison between plans must be made between options. The ITS characteristics are referred to as "elements"; there can be a variety of elements in an option. An ITS option is similar to a strategy.

When creating or modifying an ITS option, the user adds and edits an ITS option on a network by working with a comprehensive list of elements. To add an ITS element to the network, the user must provide critical information about the element. Each ITS element needs a basic set of information, such as description, year of opening, location and data specific to the type of element.

The user can also view and edit the impacts and equipment necessary for each ITS element. IDAS uses values for impacts that were taken from empirical evidence. The user can change the values, if the characteristics of the project deviate from the original source.

The equipment necessary for the ITS deployment is used in the calculation of the costs generated for the option. Also, if the costs provided by IDAS are not correct for the specified equipment, the user can update the costs of the equipment.

After all the characteristics, impacts and the equipment have been defined IDAS calculates benefits and costs. To do this, IDAS first performs an equilibrium traffic assignment to obtain volume and speed estimates on all highway links in the network. IDAS might also perform mode split to obtain transit ridership or deflect peak-period trips to off-peak times.

When the Benefit module is run, the user can ask for different kinds of outputs, including travel times, total emissions, total energy consumption, safety, etc. Benefits can be expressed in dollars. The Cost module calculates construction, design and maintenance costs for the ITS equipment. IDAS also has an alternatives comparison module, which allows the user to compare the different alternatives and options that has been created.

The following page lists those ITS strategies that IDAS is capable of evaluating.

IDAS employs algorithms adopted from conventional travel forecasting theory, but does not extend the theory in any important way. The underlying processes should be familiar to anyone who has performed travel forecasts in an urban area. IDAS differs from a conventional travel forecasting model by providing user access to a wealth of empirical evidence about the benefits and costs of ITS strategies and integrating this evidence with the travel forecasting theory.

IDAS is capable of analyzing this list of ITS components:

Arterial Traffic Management Systems
Isolated Traffic Actuated Signals
Preset Corridor Signal Coordination
Actuated Corridor Signal Coordination
Central Control Signal Coordination
Emergency Vehicle Signal Priority
Transit Vehicle Signal Priority

Freeway Management Systems
Pre-set Ramp Metering
Traffic Actuated Ramp Metering
Centrally Controlled Ramp Metering

Advanced Public Transit Systems
Fixed Route Transit – Automated Scheduling System
Fixed Route Transit – Automatic Vehicle Location
Fixed Route Transit – Combination Automated Scheduling System and Automatic Vehicle Location
Fixed Route Transit – Security Systems
Paratransit – Automated Scheduling System
Paratransit – Automatic Vehicle Location
Paratransit – Automated Scheduling System and Automatic Vehicle Location

Incident Management Systems
Incident Detection/Verification
Incident Response/Management
Incident Detection/Verification/Response/Management combined

Electronic Payment Systems
Electronic Transit Fare Payment
Basic Electronic Toll Collection

Railroad Grade Crossing Monitors

Emergency Management Services
Emergency Vehicle Control Service
Emergency Vehicle AVL
In-Vehicle Mayday System

Regional Multimodal Traveler Information Systems
Highway Advisory Radio
Freeway Dynamic Message Sign
Transit Dynamic Message Sign

Regional Multimodal Traveler Information Systems (continued)
Telephone-Based Traveler Information System
Web/Internet-Based Traveler Information System
Kiosk with Multimodal Traveler Information
Kiosk with Transit-only Traveler Information
Handheld Personal Device – Traveler Information Only
Handheld Personal Device – Traveler Information with Route Guidance
In-Vehicle – Traveler Information Only
In-Vehicle – Traveler Information with Route Guidance

Commercial Vehicle Operations
Electronic Screening
Weigh-in-Motion
Electronic Clearance – Credentials
Electronic Clearance – Safety Inspection
Electronic Screening/Clearance combined
Safety Information Exchange
On-board Safety Monitoring
Electronic Roadside Safety Inspection
Hazardous Materials Incident Response

Advanced Vehicle Control and Safety Systems
Motorist Warning – Ramp Rollover
Motorist Warning – Downhill Speed
Longitudinal Collision Avoidance
Lateral Collision Avoidance
Intersection Collision Avoidance
Vision Enhancement for Crashes
Safety Readiness

Supporting Deployments
Traffic Management Center
Transit Management Center
Emergency Management Center
Traffic Surveillance – CCTV
Traffic Surveillance – Loop Detector System
Traffic Surveillance – Probe System
Basic Vehicle Communication
Roadway Loop Detector
Information Service Provider Center

Generic Deployments
Link-based
Zone-based

Here are three flow diagrams that illustrate how IDAS works.

Figure 5. ITS Deployment: Emergency Vehicles AVL

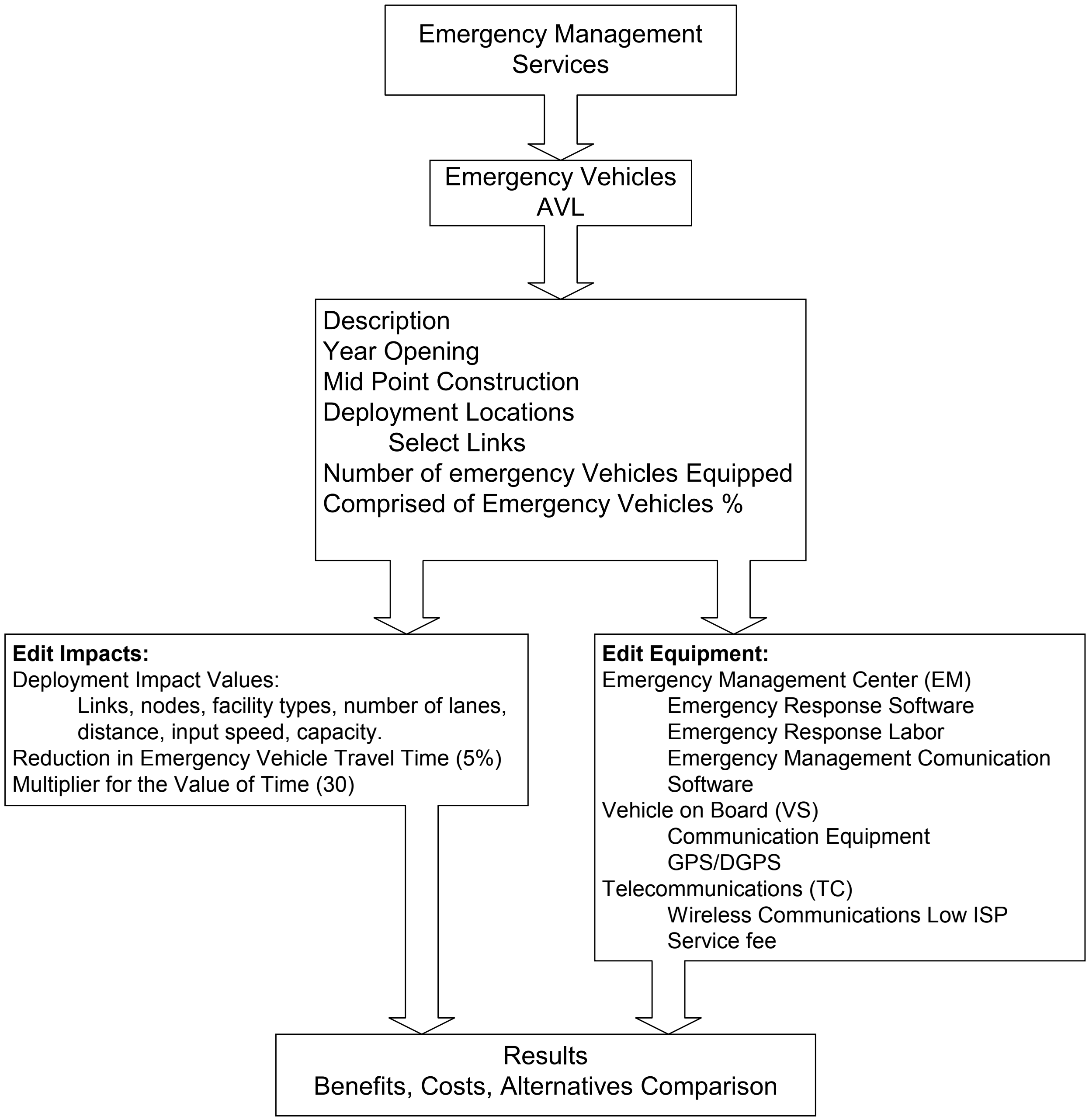


Figure 6. ITS Deployment: Traffic Actuated-Isolated

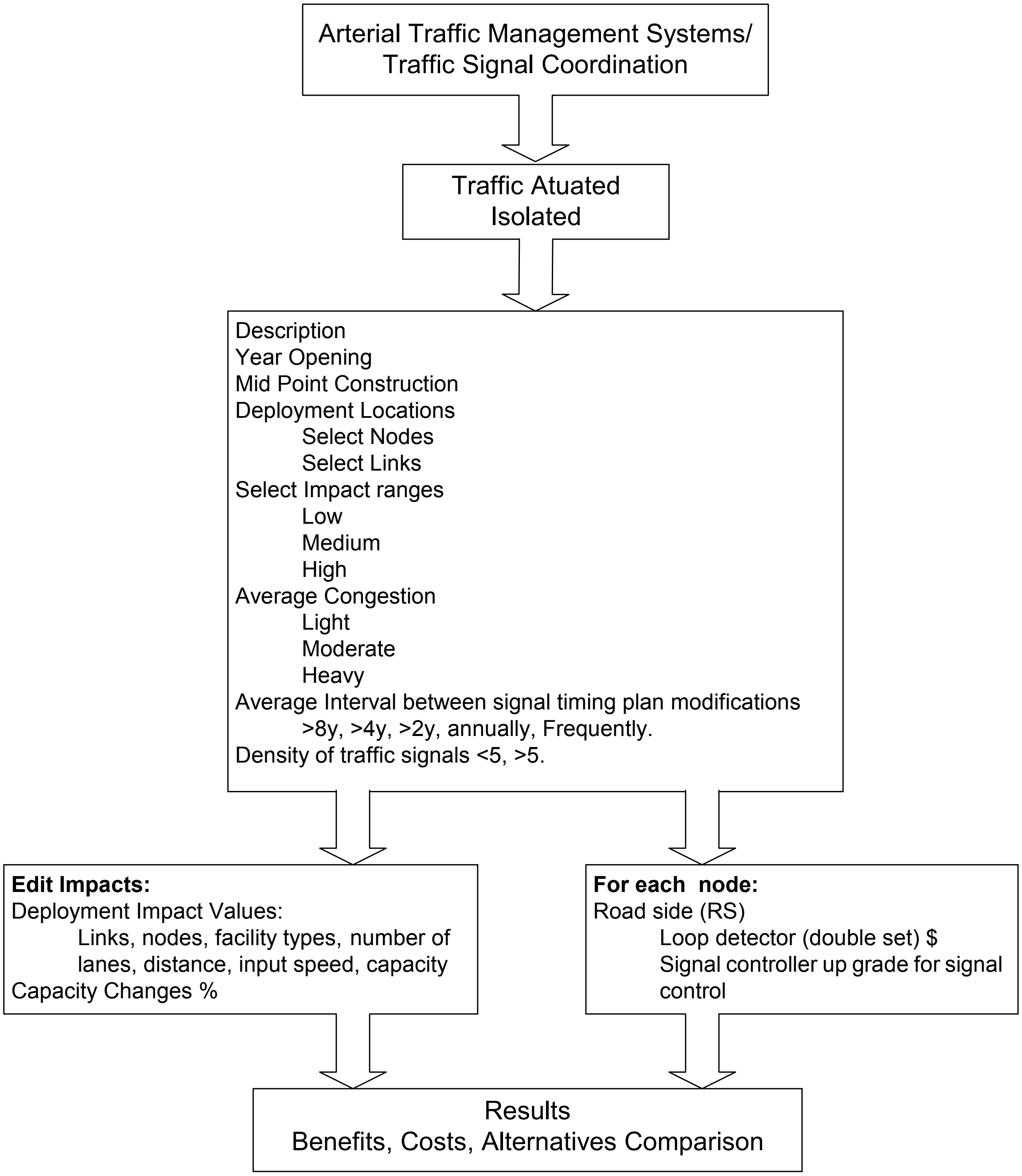
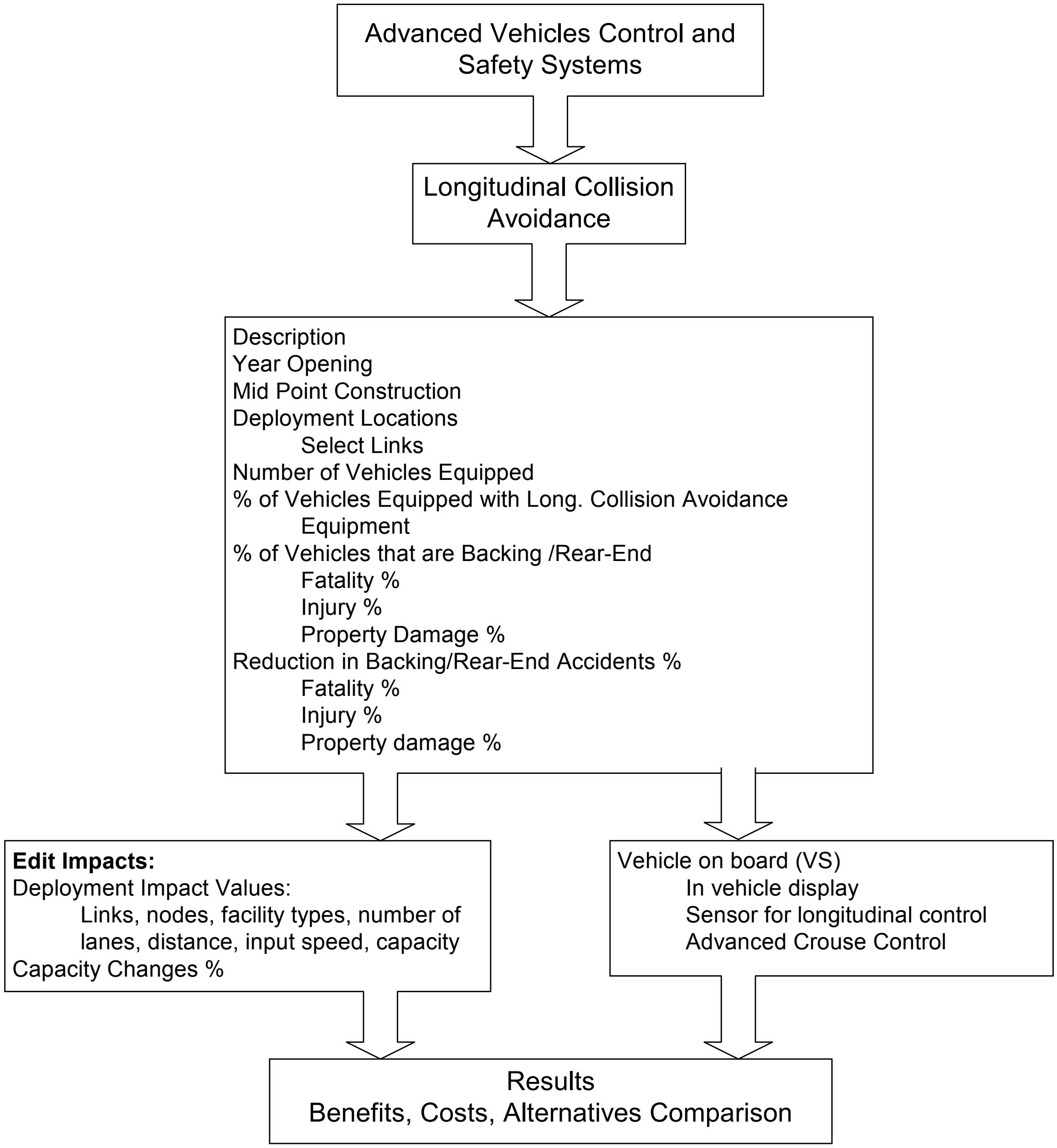
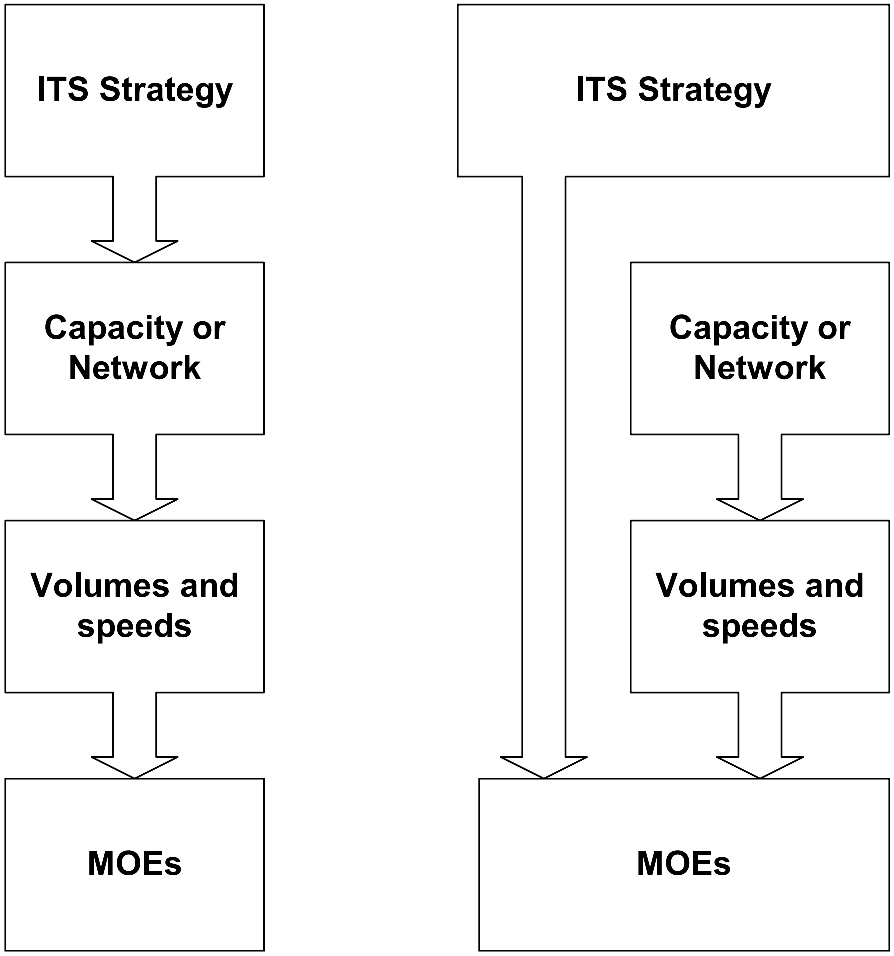


Figure 7. ITS Deployment: Longitudinal Collision Avoidance



As can be seen in the examples, IDAS can work in fundamentally two different ways as is shown in the next figure.

Figure 8. Two Ways that IDAS Evaluates ITS Strategies



Depending in the ITS strategy and based in the empirical evidence that IDAS contains, MOEs can be affected directly or through the network characteristics.

A sizable number of ITS deployments were tested in IDAS to see the effect that different ITS elements would have. Appendix A summarizes these tests.

After testing with IDAS with a wide range of ITS deployments, the following advantages and disadvantages were perceived.

Advantages

- IDAS has an outstandingly broad collection of empirical evidence from many different ITS implementations. The empirical evidence is linked to the software in a manner that allows the user to quickly obtain the necessary data and assumptions for the project, alternative and option under consideration.
- The user interface is very well designed for the purpose. The software makes excellent use of the Windows GUI (graphical user interface) to display ITS deployments on the

network and to edit assumptions and data. The user-interface, for the most part, is logical and self documenting.

- For new software of this complexity, IDAS is very stable.
- The software is refreshingly flexible in allowing users the possibility of changing most of the default values to adapt the software to local project characteristics.
- IDAS has a full range of equipment options necessary for ITS deployments.
- IDAS permits users to update costs to reflect changing technology or local conditions. IDAS also allows users to update information on how MOE's are calculated.
- IDAS provides an effective means of comparing alternatives.
- IDAS provides a conventional traffic assignment model and a mode split model to determine the effects an ITS strategy might have on traffic rerouting and transit ridership. IDAS also has mechanisms for dealing with induced demand and peak-spreading.
- IDAS monetizes impacts, so they can be directly compared with costs. IDAS does not appear to calculate consumer surplus, which would be required for assessing any alternative with large changes in travel demand.

Disadvantages

- The documentation for IDAS is missing many technical details and the user interface hides much of the calculation, so it is often difficult to determine exactly what IDAS is doing with an option. In addition, there appears to be considerable amount of judgment exercised in converting empirical evidence into ways that IDAS can use that evidence. Many users would consider IDAS a "black box".
- IDAS is extremely limited in its ability to assess the effect of traffic control devices. IDAS's usual method of handling a traffic control device is to increase or decrease the capacity parameter in a BPR travel-time/volume formula for a link. Thus, traffic flow theory is not used. It is highly unlikely that the impacts of traffic control devices will be simulated with any degree of accuracy. Traffic control devices not correctly modeled in IDAS, but found in a typical traffic operations model, include: isolated signals, coordinated signal systems and ramp meters. Furthermore, IDAS is incapable of representing queuing.
- IDAS is disconnected from the travel forecasting model that provides trip generation and trip distribution information. While this is of little concern from a strategic planning perspective, it can have major implications when doing long-range planning. There is a possibility that an aggressive ITS deployment could have implications for travel demand that would be best modeled at the trip generation and trip distribution stages.
- IDAS is static with a one-hour period of analysis. Peaking within an hour cannot be considered, and the analysis of short-lived hotspots, such as incidents or localized recurring congestion, cannot be performed.
- Delay in uncontrolled segments is calculated with the BPR curve. The BPR curve is unlikely to properly represent many common highway geometries, such as ramp merging areas and weaving sections. In addition, the BPR curve, as implemented in IDAS, would be incapable of properly representing two-lane roads (in either rural or urban settings) or roundabouts.

- IDAS appears to find strictly equilibrium assignments. Partial equilibrium conditions that might be due to imperfect knowledge or limited compliance with a traffic advice cannot be handled. IDAS cannot incorporate route-choice criteria other than travel time.

Conclusions about IDAS

Despite its size and cost, IDAS is clearly intended as a sketch-planning tool for places that already have updated conventional travel forecasting models. IDAS should be a much better tool for understanding the costs and benefits of ITS than spreadsheet methods, because it can analyze the rerouting of traffic. However, IDAS is deficient in its ability to forecast traffic impacts and to determine how those impacts might affect demand.

Because of the sketchy technical documentation provided with IDAS it is not possible to fully critique its ability to accurately assess many ITS strategies.

Travel Forecasting with Integrated Macroscopic Traffic Simulation: QRS II

What is QRS II?

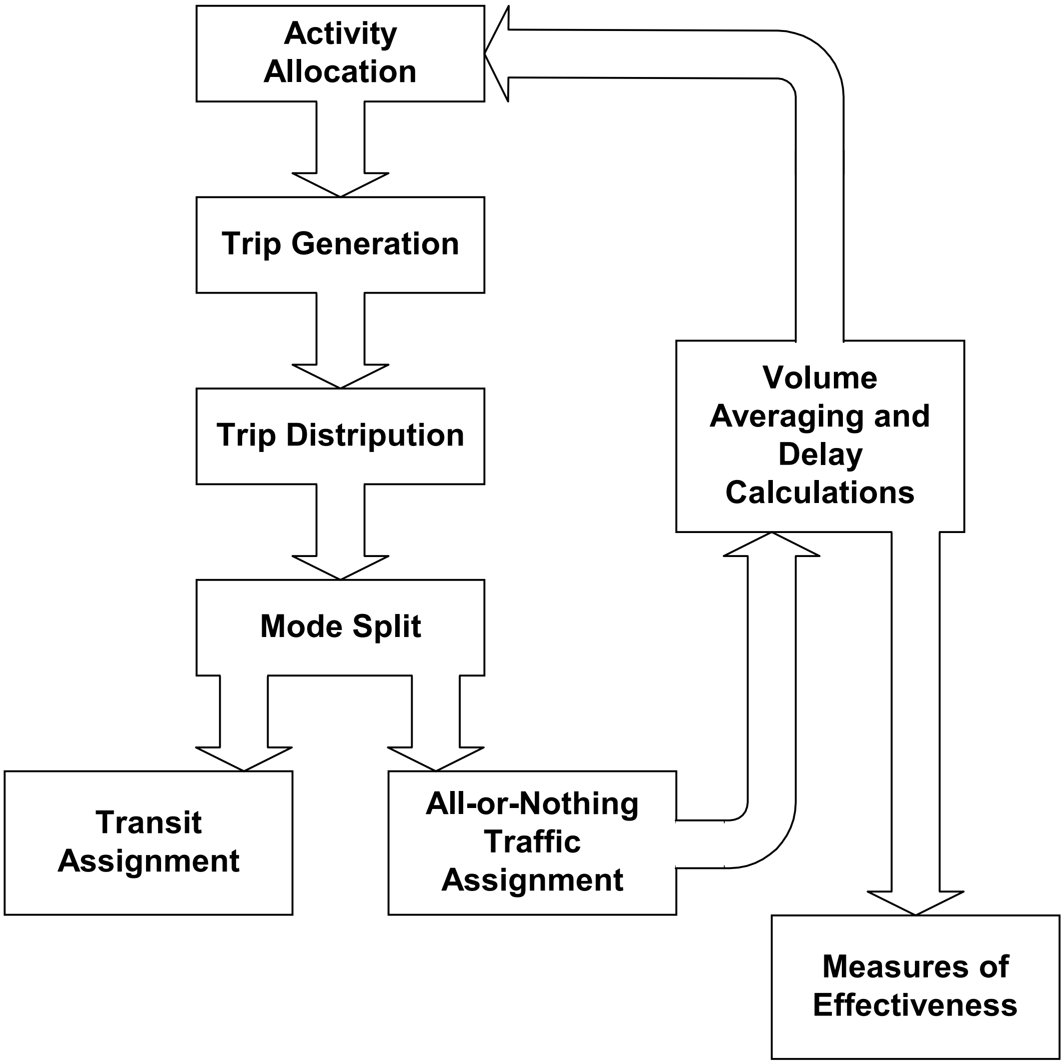
QRS II (Quick Response System II) is an example of a four-step travel demand simulation package with an integrated macroscopic traffic simulation. For many years, QRS II was alone in its class, but other travel forecasting packages are now adopting similar capabilities. QRS II is a commercial product.

QRS II was written by an author of this report, so its capabilities can be evaluated with more precision that the other three software packages in this section. This discussion is limited to the stock version of QRS II. Because QRS II's source code is available to the project team, there is potential for increasing its capabilities and customizing the package to meet project needs. In addition, there are versions of QRS II that have already been customized for research purposes, but the capabilities of those versions will not be addressed here.

How Does QRS II Work?

QRS II is a travel forecasting software package similar to many others being used by metropolitan planning organizations throughout the US, but contains traffic operational analysis procedures from the Highway Capacity Manual and other sources. QRS II contains the major four steps: trip generation, trip distribution, mode split and trip assignment (both for highways and generalized transit). See Figure 9 for a flow diagram of conventional travel forecasting models, including QRS II.

Figure 9. Major Steps in the Operation of QRS II



On the demand side, QRS II has default trip generation procedures from NCHRP #187 and #365[1], but has an ability to handle almost any trip generation model through user-supplied mathematical expressions. Trip distribution uses the "gravity model"[2] and mode split is performed with a multinomial logit model[3] (automobile, generalized transit, and a user-defined

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[1] NCHRP #187 and #365 are reports from the National Cooperative Highway Research Program that contain many "transferable parameters" for travel forecasting and suggest procedures for performing routine travel forecasting in metropolitan areas.

[2] A gravity model is a widely used method of trip distribution that is somewhat analogous with Newton's law of gravity. The gravity model allocates trips between pairs of zones in proportion to the levels of trip making activity in each zone and in proportion to a measure of proximity between the zones.

[3] A multinomial logit model is a widely used method of mode split, where the proportion of people choosing a mode is based on the utility (a measure of travel time, cost and convenience) of the mode.

"third mode"). The default automobile occupancy[1] step applies factors to person trips that can vary by time of day, but customized automobile occupancy factors can be computed with user-supplied mathematical expressions. QRS II contains an optional land-use forecasting module, so very long-range forecasts that involve substantial changes in urban development patterns may be simulated.

For traffic analysis, QRS II recognizes the existence of stop signs, yield signs, one-lane roundabouts, signals and ramp meters. QRS II cannot directly recognize any ATIS (advance traveler information systems) devices, such as variable message signs or highway advisory radio. Because QRS II is limited to the type of analyses found in the HCM, it is not possible to evaluate ITS strategies that incorporate traffic control devices that are not found in the HCM (except for ramp meters). Like most travel forecasting packages, QRS II performs static, user-optimal, equilibrium traffic assignments; however, traffic assignments are sensitive to delays caused by traffic control devices. The algorithm for equilibrium traffic assignment is the method of successive averages (MSA)[2] (Powell and Sheffi, 1982). The shortest time period of analysis is one hour.

QRS II does not contain any reference to specific ITS strategies. Thus, any ITS strategy must be reinterpreted by the user by changing input data directly.

Like IDAS, QRS II uses the BPR curve to obtain travel times on uninterrupted facilities (freeways and long, uncontrolled portions of arterial streets), which can be customized to each vehicle class. Unlike IDAS, adjustments to capacity must be made manually to individual links, as QRS II does not contain a built-in library of ITS effects on capacity.

QRS II has an option (similar to Paramics) that allows it to load traffic directly to links, bypassing centriods[3] that are essential to conventional traffic assignment methods.

QRS II is limited in its ability, as seen with Dynasmart-P, to cleanly handle disequilibrium situations (from lack of information or from driver habit) that might arise with the implementation of an ITS strategy. QRS II has the capability of combining all-or-nothing assignments with equilibrium assignments in the same run, so some disequilibrium situations may be handled in this fashion.

QRS II may be operated as if it were a subroutine of another computer program. Thus, depending upon the needs and capabilities of those using the software, it is possible to extend the range of QRS II's abilities considerably. For example, QRS II was used with another computer program to evaluate long-range deployment of traffic signals (Horowitz and Granato, 2000).

[1] Automobile occupancy is a minor step in travel forecasting model that allows conversion of person trips (used in the demand parts of the model) to vehicle trips (used in highway traffic assignment).
[2] Method of successive averages is a way of attaining a user-optimal equilibrium traffic assignment, and involves finding the unweighted average of several all-or-nothing traffic assignments, where each new all-or-nothing traffic assignment reflects the amount of delay on the network calculated from the previous average. An all-or-nothing traffic assignment sends all vehicles along the shortest path between an origin and a destination while sending no vehicles along any other path.
[3] A centroid is an artificial node that represents the beginning and end of all trips to and from a particular zone.

IDAS can read networks and trip tables created from travel forecasting packages (after being slightly reformatted), including QRS II. Thus, it would be possible to use QRS II for travel forecasting and IDAS for evaluating the costs and benefits of specific ITS strategies.

Advantages

- Because QRS II is a fully enabled four-step model it can forecast demands many years into the future. QRS II can simulate changes in urban development. Unlike the other three software packages described here, there is no need for a separate demand model.
- QRS II is able to perform equilibrium traffic assignment that is sensitive to the nature of traffic controls, as it contains operational analysis procedures from the Highway Capacity Manual. These capabilities open the opportunity for realistic evaluation of certain ITS strategies.
- QRS II can be used as a subroutine in another computer program, thereby allowing many runs of the software to be chained together. This ability may be necessary to simulate the staging of long-range ITS deployments.
- QRS II has an MOE calculator that provides estimates of vehicle emissions, vehicle-hours-traveled and vehicle-miles-traveled. QRS II also has a "tool" for calculating consumer surplus[1].
- The networks and trip tables from QRS II can be used as input data for IDAS.
- QRS II comes with its own network editor, so network-related data preparation is easier than with the other packages described here.
- QRS II has been in existence for many years and is very stable and fast.
- QRS II can handle very large networks, such as full arterial and freeway systems for major urban areas.
- QRS II can consider route choice criteria other than travel time, but those criteria would need to be translated into time units and given to the model as characteristics of links.

Disadvantages

- QRS II performs a static traffic assignment that would be less sensitive to peaking characteristics of traffic than a dynamic traffic assignment. Short-lived hotspots (such as small incidents) cannot be considered.
- ITS strategies would need to be translated into QRS II inputs (such as speeds, capacities, cycle lengths and arrival types), as QRS II does not explicitly contain any ITS strategies except ramp metering.
- QRS II is limited in its ability to model partial equilibrium traffic conditions, as would be experienced with the implementation of variable message signs.
- QRS II cannot calculate costs of ITS strategies.
- QRS II does not automatically compare alternatives and it does not monetize any of the benefits or net benefits.

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[1] Consumer surplus is the difference between a person's willingness-to-pay and the price. The total amount of consumer surplus in a transportation system is a commonly used MOE and it can be computed from the outputs of a travel forecasting model.

- Alternatives that involve transit require a separate transit network. QRS II would also have difficulty simulating HOV (high occupancy vehicle) lanes and special routing characteristics of carpools.
- Delays on uncontrolled road segments are calculated with the BPR curve. Thus, the ability to model delays within ramp junctions and merging areas is limited. This limitation may be a problem for evaluating any ITS strategy that affects capacity in such sections.

Conclusions about QRS II

Unlike the other three software packages reviewed here, QRS II as a representative of a four-step travel forecasting package has the ability to perform long-range traffic and transit forecasts. QRS II can also realistically model traffic conditions, but lacks traffic dynamics and explicit ITS elements. QRS II's macroscopic traffic simulation capabilities are less flexible than the microscopic capabilities in Paramics.

Mesoscopic Traffic Simulator with Dynamic Traffic Assignment: Dynasmart-P

Dynasmart-P is an example of a mesoscopic traffic simulation with dynamic traffic assignment. Dynasmart-P is one of two, essentially duplicative, software products being developed by the TrEPS project sponsored by the Federal Administration. We have been provided with an alpha test version for evaluation purposes. Its forerunner, Dynasmart, has been used for many years at the University of Texas at Austin and elsewhere for research purposes.

What is Dynasmart-P?

Dynasmart-P is a software package that allows users to simulate and evaluate the design and planning of traffic in intelligent transportation networks. The software is able to simulate most driver behavior within a network, such as variations of traffic flow patterns over time and routing decisions of drivers. Dynasmart-P can calculate for many short time slices the speeds, densities, queues, vehicles trajectories and different characteristics of each link in the network. The software has capabilities to evaluate an array of operational strategies, including ATMS strategies, HOV facilities, ramp meters and special use lanes. Dynasmart was developed for short-term forecasting of traffic in real-time; Dynasmart-P is a version of Dynasmart for the purposes of traffic planning. A mesoscopic simulator is theoretically faster than a microscopic simulator, such as found in Paramics, so that it would be possible to operate a simulation of a traffic network substantially faster than real time.

How Does Dynasmart-P Work?

Dynasmart-P simulates intelligent transportation networks using two different methods of vehicle generation. The first method requires the user to specify origin and destination matrices (aggregated to zones) for different demand time slices. The second requires the user to specify the characteristics of vehicles, their stops and their corresponding travel times.

The vehicles generated can be assigned in two different ways. The first way is "one step simulation assignment", in which all vehicles are individually assigned to its currently best path, a random path among a limited set of shortest paths or any predetermined path. The second way is “iterative simulation assignment” in which Dynasmart-P applies dynamic user-optimal equilibrium assignment using the method of successive averages (MSA). MSA is applied to time slices as short as 1 minute, with different demands and different network characteristics applicable to each slice.

Dynasmart-P is able to evaluate traffic management strategies such as ramp metering, variable message signs (VMS) and path and corridor coordination. Dynasmart-P also can calculate the congestion pricing for regular links, HOV links and HOT (high occupancy toll) links. It can simulate incidents, including their starting time, ending time, location and severity.

Dynasmart-P also has the ability to find system optimal traffic assignments, which can serve as upper bounds on the benefits that might be achieved by rerouting traffic to avoid incidents or other random traffic events.

Ramp Metering: Dynasmart-P assumes that ramp metering follows the ALINEA procedure. ALINEA is a traffic responsive feedback process where the metering rate is set according to the occupancy[1] at a downstream point on the mainline. To evaluate ramp metering in a network it is necessary to create a text file in which the following data items need to be included: number of ramps, the frequency in which the ramp metering is checked by the simulator and the location of two detectors[2] downstream from the meter. Dynasmart-P also asks for two constants required by ALINEA for each ramp that are used to determine the ramp’s meter rate. The first constant is the target occupancy (defaulted to 0.2); ALINEA will adjust the metering rate in an attempt to achieve this occupancy value. The second constant relates to how much the metering rate changes for a given difference between the actual occupancy and the target (defaulted to 0.32 vehicles per minute per lane per difference in occupancy from target). Also required are the time slices in which the ramp metering is effective and the ramp saturation flow rate. Refer to the Table B.1 in Appendix B (taken from the Dynasmart-P user’s manual) for the data format of the ramp metering file.

Variable Message Signs (VMS): *Variable message signs are entered in the network for a selected link. Dynasmart-P models three different types of messages: speed advisory, route advisory and congestion warning. Each message has it own starting and ending time input for the user.*

- For the speed advisory messages there is a threshold speed that is specified by the user. This threshold can be positive or negative. Dynasmart-P will increase or decrease the speed on the link by that percent.
- For route advisory messages a path number (among K shortest paths) is specified by the user that indicates where vehicles will divert. In addition, it is necessary to indicate which vehicles are affected by the message: vehicles bound for all destinations or just one destination.

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[1] Traffic occupancy is the percent time that a detector is occupied. Traffic occupancy should not be confused with vehicle occupancy, which is the number of people in a vehicle.

[2] A detector is a device for measuring traffic flow. A common type of detector is a loop detector that is embedded in the pavement below a travel lane. A loop detector can measure volume and occupancy (the percent of time that the detector is occupied). Two detectors in the same travel lane can be used to measure speed.

- For congestion warning messages the percent of VMS responsive vehicles on a specific link is specified. They will be rerouted to another path, either the current best path or a random path among the K-shortest paths.

Table B.2 in the Appendix is taken from the Dynasmart-P user's guide has details on VMS data formats.

Incidents: Dynasmart-P allows modeling of incidents and work zones. The effect of these situations is handled by a fractional reduction in the capacity of a link. Also required are the starting and ending times. Complete link blockage cannot be simulated. Refer to Table B.3, taken from Dynasmart-P user's guide, which describes the data format of the incident file.

Pricing (HOV/HOT lanes): Dynasmart-P can also simulate the effect of congestion pricing. It is necessary that the users input the cost of an LOV (lower occupancy vehicle) or an HOV using the HOT lanes, the cost of traversing typical links in the network and the dollar value of time. Refer to Table B.4 to see details of the pricing file.

Advantages

- Dynasmart-P is very precise in its ability to model short-lived problems and peaks in traffic volumes.
- Dynasmart-P is flexible in how it can simulate and evaluate the trajectory of vehicles through the network. It can use an origin-destination matrix of vehicle trips or it can simulate the path of each vehicle with intermediate stops and their durations.
- The software computes the variation of queue length, traffic densities, traffic speeds and other characteristics over time for each link in the network. Dynasmart-P is able to show graphically the MOEs during the time for a selected link and the entire network.
- Dynasmart-P contains a variety of logical algorithms for the assignment of vehicles to the network. The vehicles can be assigned to a determined path (best path, random path among K shortest paths or any predetermined path) or a path found by applying equilibrium assignment.
- Dynasmart-P can be produce user optimal equilibrium assignments, system optimal equilibrim assignments and non-equilibrium assignments.
- Dynasmart-P is able to deploy and evaluate the effect of important ITS strategies, such as VMS, HOT lanes, congestion pricing and incident management.
- Dynasmart-P allows users to change parameters for specifics scenarios, such as the fraction of responsive or unresponsive vehicles for a determined strategy.
- Dynasmart-P has been developed over a number of years and has been used in many research projects. Its features have been described in many technical documents and its developers have a very open attitude about disclosing the technical details of its features.

Disadvantages

- Dynasmart-P lacks long-range traffic forecasting capabilities; such forecasts must be transferred from other software.
- Dynasmart-P does not forecast transit ridership.

- The Dynasmart-P software requires text files for all its data inputs. Convenient network or data editors are not available at this time, although it is possible to edit many text files within Dynasmart-P's GUI. The time and resources necessary to code a network from scratch and provide all the necessary input data are substantial. Network data can be converted from other sources, such as a GISs, CORSIM, and several planning models.
- Because of the need for trip tables for multiple time slices and extensive descriptions of street geometry and traffic controls, data requirements go well beyond what is typical of long-range transportation planning software.
- The software allows planners to evaluate some but not all the ITS strategies that can be placed on a network. Missing strategies include advanced vehicle control and safety systems and emergency management systems. To simulate a wider range of strategies, it would be necessary to crudely make IDAS-like adjustments to link speeds and capacities.
- To effectively use the dynamic aspects of the software, it is necessary to supply complete OD tables for very small time slices. Dynasmart-P eases this data requirement somewhat by allowing the user to factor a static OD table into time slices, but it does not contain algorithms for creating a static OD table from planning data.
- To effectively use its features relating to driver response to variable message signs, it is necessary for the user to identify individual paths for trips, but such data would be very difficult to create for long-range forecasts.
- Dynasmart-P simulates only one type of ramp metering. Since delays at ramps are highly dependent on the ramp metering algorithm, Dynasmart-P is unlikely to give dependable delay estimates for freeway systems employing algorithms other than ALINEA.
- Dynamsmart-P's mesoscopic traffic simulator is slower than a macroscopic delay calculator, which would be a drawback when embedding the travel forecasting model within a decision making framework.
- Equilibrium traffic assignments with Dynasmart-P requires treatment of multiple time slices, which would be slower than can be achieved with a static traffic assignment routine such as found in IDAS and QRS II.
- Dynasmart-P cannot calculate costs of ITS strategies.
- Dynasmart-P does not automatically compare alternatives and it does not monetize any of the benefits or net benefits.

Conclusions about Dynasmart-P

Dynasmart-P has a very advanced dynamic traffic assignment (DTA) algorithm that can simulate a very wide range of traffic conditions, both equilibrium and non-equilibrium. Dynasmart-P has mesoscopic traffic simulation capabilities, which would likely be less accurate than Paramics. It is uncertain whether Dynasmart-P's traffic simulation can outperform the macroscopic routines, such as those in QRS II that are based on the Highway Capacity Manual. Execution speed is a concern, as well as the lack of long-range travel forecasting capabilities.

Microscopic Traffic Simulator and Routing: Paramics

Paramics is one example of a traffic microsimulation software package, of which there are many available. Paramics was selected for review here because it is the package adopted by Wisconsin WisDOT for its current evaluation of the Milwaukee area freeway system.

What is Paramics?

Paramics is a software tool used to microsimulate traffic flow and operations. Traffic demands are given to Paramics in the form of a zone-to-zone OD (origin-destination) matrix. The software simulates the movements and behavior of individual vehicles on a given traffic network. Paramics has three parts: a Modeller, a Processor and an Analyzer. The Modeller uses a GUI (graphical user interface) to visualize the simulation of the traffic flow on the network. The Processor simulates the traffic situation without the GUI, thereby increasing simulation speed when numerous tests are required. The Analyzer reads and analyzes the simulation outputs, providing graphics to compare the results.

How does Paramics work?

To perform the traffic simulation, Paramics requires a time-dependent OD matrix. The trips are represented from zone to zone and are separated into vehicle types and into (as small as 5 minutes)-time slices. Vehicle trips are not loaded at centroids but directly to links. The number of trips between an origin and destination is used to create a probability that a trip is made during a time slice, so that vehicle trips can be randomly created. Parking lots can be used as origin or destination points.

A traffic assignment is applied to all vehicles except fixed route vehicles, such as buses. Route choice in Paramics depends upon network coding, link cost factors, sign posted routes, lane and turn restrictions, model parameters, generalized cost coefficients, percent of familiar drivers and default parking origin/destination assumptions.

A major feature of Paramics is its application programmer's interface (API) that allows customization of the simulation to local traffic controls, conditions and future ITS options.

Paramics uses one of three assignment methods: stochastic, dynamic feedback or all-or-nothing.

- *All-or-nothing assignment*: This assignment method assumes that drivers traveling from zone A to zone B choose the same shortest path using a cost function based on free flow speed, distance and tolls. Paths choice is also influenced by assumptions about driver familiarity with the route.
- *Stochastic*: This assignment method chooses paths randomly for each vehicle based on assumptions about driver's perceptions of the shortest path and variability in travel costs. Path choice is re-evaluated at every node encountered along the trip.
- *Dynamic Feedback*: At each time slice the amount of congestion is estimated. The algorithm re-routes the remaining parts of a trip for a familiar drivers, given assumptions about the driver's perceptions of the new traffic situation.

Driver Behavior: Paramics documentation states: "The movement of individual vehicles is governed by three interacting models representing vehicle following, gap acceptance and lane changing. Vehicle dynamics are relatively simple, combining a mixture of driver behaviour and some limitations based on vehicles' physical type and kinematics (e.g., size, acceleration/

deceleration). These models are applied simultaneously at the level of individual vehicles." Consequently, each simulation is unique; i.e., the same inputs can have different results.

Geometry and Controls: Paramics allows a wide variety of road geometries, vehicle restrictions and intersection controls to be placed on the network, including detector locations. Paramics does not provide for a large array of ITS elements. However, Paramics can create random incidents and evaluate the performance of the traffic systems with such incidents. Paramics also has the capacity to simulate the effects of variable message signs, provided that the user specifies a set of compliance rules. Unlike some other microsimulation packages, Paramics can handle very large arterial networks.

Ramp Metering in Paramics: A Paramics simulation laboratory document in describes ramp metering methods:

"Paramics provides users with an Application Programming Interface (API) through which users can customize and extend many features of the underlying simulation model. Based on provided API functions, users can further develop an external or complementary module, or their own API functions to implement or test an ITS application without having to deal with the underlying proprietary code."

Paramics sets the timing for actuated signals by programming language code, specified by the user, that controls temporary and permanent changes to timings. For each particular signal, the user must design a plan. The plan includes a set of loops and an optional set of parameters. Each plan is given the phases that would be controlled by that plan. The programming language is C-like. The "if-the-else" statements are used in this language.

The following is an example of ramp metering taken from the Paramics Modeller user guide:

Example: Ramp metering with a parameter.

```
Plan count 1
Plan 1 definition
Loops 1
Parameters 1
If (init) { variable; }
If (occupied[1])
{
.       red3 = parameter[1];
}
else
{
        red3 = 0;
}
```

This plan assumes a two-phase signal, with one phase all green (red time is zero) and the other phase all red (green time is zero). This plan is applied to the all red phase. A fixed-time ramp metering policy is implemented if a vehicle is detected on a loop. If no vehicle is present the signal is on green permanently, which is equivalent to “meter-off” conditions.

Advantages

- Paramics permits users to simulate a full range of situations that are found daily in a traffic network. Paramics can simulate urban and freeway networks or mixed intersections with advanced signal control or roundabouts, ramp metering, public transportation, parking, incidents, truck-lanes, high occupancy vehicle lanes and more.
- Paramics allows users to rapidly simulate different deployments when required. When it is necessary to compare different alternatives in a short time, Paramics’ Processor (without the GUI) could be used.
- Paramics is able to represent the traffic assignment in the network by using one of the three assignment methods.
- Paramics allows users to build the network using its own graphical user interface.
- Of all the models reviewed here, Paramics’ underlying theory should provide the most realistic simulation of traffic on individual links and at individual nodes and the greatest flexibility to model a variety of traffic situations. However, it would be difficult to tell the qualitative difference between Dynasmart-P and Paramics without real-world tests on the same highway network. (The behavioral mechanisms in Paramics have not been compared with other microsimulation packages, such as CORSIM or Transims.)
- Like Dynasmart-P, Paramics works in small time slices, allowing the modeling of short-lived incidents and hotspots.
- A limited range of ITS strategies can be simulated, including variable message signs and some aspects of incident management. The API is flexible enough to allow simulation of other ITS strategies.
- Paramics allows a variety of ramp metering schemes.
- Paramics prepares a very detailed description of traffic performance, including a complete set of MOEs and queue lengths.

Disadvantages

- Paramics does not contain any algorithms for forecasting traffic demand, so an external source of demand information is required.
- Paramics does not have transit ridership forecasting capabilities.
- Data input requirements are substantial. While Paramics provides a network editor, much of the data input is in the form of text. Data requirements go well beyond what is typical of long-range transportation planning software.
- It is necessary to supply complete OD trip tables for very small time slices, but Paramics does not contain algorithms for creating such OD trip tables. In one example application described on the Paramics web site, OD trip tables were created with a conventional travel forecasting model (similar to the hybrid model class described earlier).
- Although no direct comparisons were made, it is likely that Paramics would take substantially longer than IDAS and QRS II to complete a simulation because of its need to microsimulate each vehicle in the traffic stream. Whether Paramics would take longer than Dynasmart-P depends upon options in both software packages.

- Paramics does not evaluate the costs or benefits of ITS elements.
- Paramics does not automatically compare alternatives and it does not monetize any of the benefits or net benefits.
- Paramics does not perform an equilibrium assignment, so the routing of vehicles may not fully reflect the amount of congestion on the network.
- Paramics does not have a large variety of stock ITS equipment options that can be tested in a simulation. Without use of the API, Paramics is limited to simulating the effect of incidents and variable message signs on the network.

Conclusions about Paramics

Paramics should provide an accurate simulation of traffic on individual links and at individual nodes, but it cannot readily handle vehicle routing under equilibrium conditions. Its speed of execution is a concern, as well as its lack of travel forecasting capabilities. Paramics has only a limited ability to model ITS elements explicitly, although power users may be able to extend Paramics' ITS capabilities through its API.

Discussion of Software

All of the software packages assign an origin destination matrix to a network and then assess the traffic impact by computing delays. Beyond these few common features, the models differ considerably in their ability to model traffic impacts of ITS elements.

Each of the four software packages is a good representative of its class, but none of the software tools are well suited for long-range ITS deployment planning. The most important deficiencies across all software packages relate to staging, realism, alternative selection, adaptiveness, traffic optimization, and randomness.

Staging. All of the software packages can simulate the effects of a policy change or a deployment of equipment at a single future point in time. None of the software packages are able to simulate a sequence of deployments where the decisions in some distant future year are dependent upon outcomes in an earlier future year.

Realism of Traffic Simulation across a Wide Spectrum of ITS Strategies. Some software packages, particularly those based on dynamic traffic assignment (such as Dynasmart-P), are able to correctly simulate the traffic impacts of a small set of ITS strategies. Other software packages, such as IDAS, can only approximate the traffic impacts of a very large set of ITS strategies. No software package exists that can correctly simulate a wide spectrum of ITS strategies.

Alternative Selection. None of the software packages are able to choose an optimal combination of ITS elements or even a reasonably good combination. Each alternative must be prepared using planner and engineer judgments. Furthermore, none of the software packages can automatically make tradeoffs between ITS and conventional strategies.

Adaptiveness. The software packages, for the most part, are not adaptive beyond allowing for actuated signals. That is, the software cannot make many of the routine and rationale judgments that a traffic engineer would make about highway geometry and traffic controls. For example, the software cannot determine for a future year when a signed intersection should become signalized or when signalized approach should get a left-turn bay. QRS II is limited to the setting of signal phases and green times in response to forecasted traffic levels.

Optimization of Traffic Operations: None of the software packages optimizes the operation of existing facilities, such as is done with SOAP, FREQ, PASSER-II or TRANSYT-7F. The ability to optimize would further improve the software's ability to simulate future optimization actions by traffic engineers.

Random Effects. The strength of ITS relates the enhanced ability of traffic engineers to respond dynamically to changing situations on highway or transit systems. Many of these changes are random and largely unpredictable. For example, the location, duration and severity of incidents are all random processes. None of the models, with the possible exception of single, isolated incidents in Paramics, adequately addresses the possibility of random effects or determines how MOEs might improve if ITS strategies are implemented to mitigate the impact of those effects. It is important to observe that true random effects in models will cause randomness in MOEs, perhaps making it difficult to compare alternatives.

Specification of a Travel Demand Forecasting Model for Developing Long-Range ITS Deployment Strategies

Forecasting Model Specification

Although the current set of software tools falls short of what is needed for long-range ITS deployment planning, it is possible to build upon the available software to create a computer program that comes closer to the needs of the problem. The quality of ITS deployment plans is closely related to the accuracy and ease of use of the traffic simulation model, and this report later demonstrates that an adequate model can be created.

Figure 10 shows a flow diagram of a dynamic travel forecasting model (DTFM) that would address many of the criticisms of the four traffic simulation packages reviewed earlier. The DTFM is designed to be embedded within a staged, long-range decision process and represents a single ITS alternative applied to a single traffic situation in one of several possible years. Because of the need to run the DTFM many, perhaps thousands, of times, it is essential that extraneous steps are eliminated and time-consuming calculations are avoided or replaced by more efficient routines. Two of at least three loops are shown in Figure 10: a time-slice loop and an equilibrium loop.

Operationalizing the Travel Forecasting Model

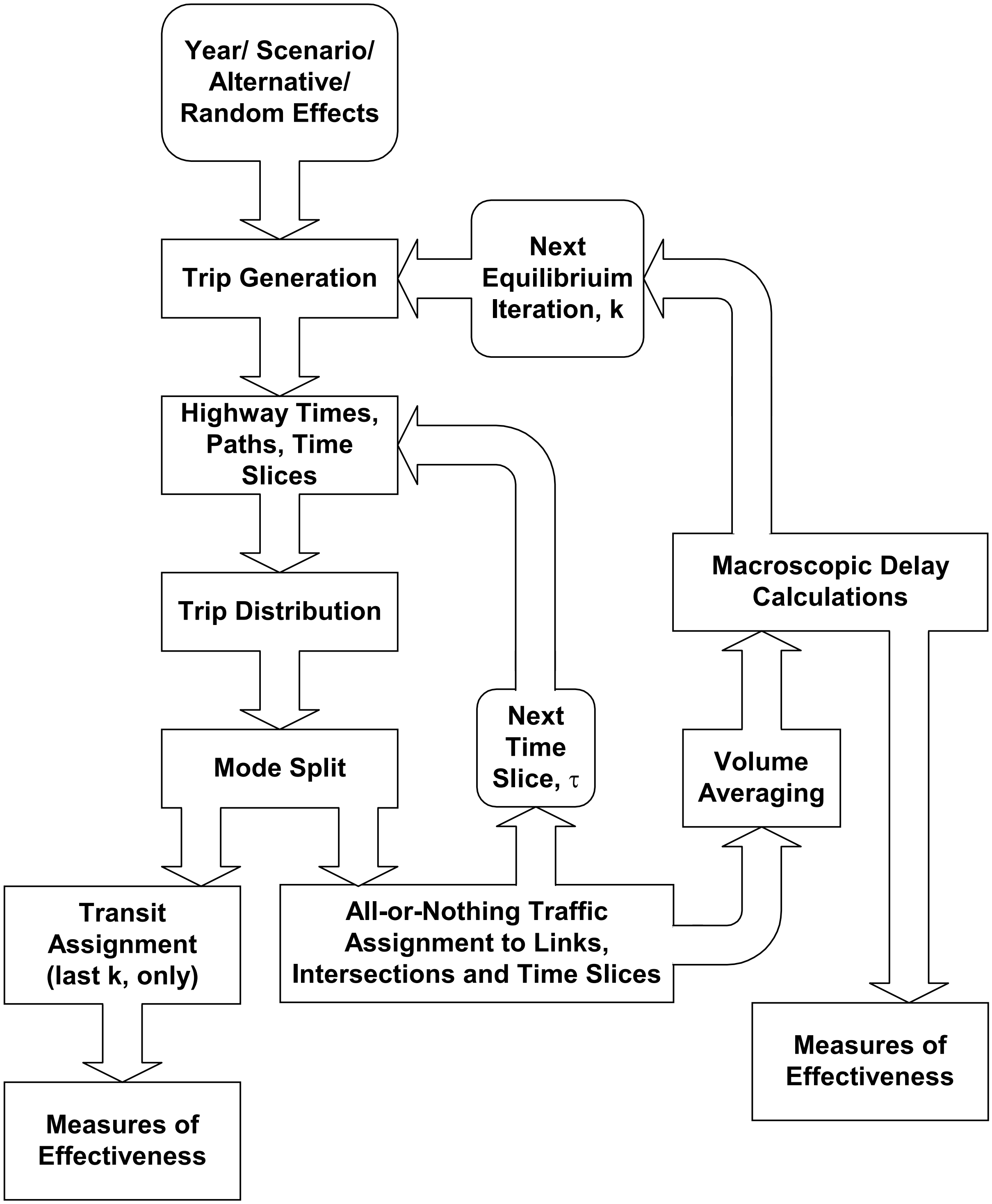
The model of Figure 10 was operationalized, experimentally, in software by modifying QRS II. QRS II was selected principally because (1) the source code was available and familiar to the project team (2) modifying QRS II would likely require fewer changes to the existing computer program than modifying either IDAS or Dynasmart-P, (3) QRS II is already a travel forecasting model, so many of the required input data for IDAS or Dynasmart-P are internally calculated, and (4) QRS II can be readily imbedded as a subroutine in another computer program. By selecting QRS II we are principally giving up the ability of IDAS to automatically evaluate the costs and benefits of an ITS strategy and giving up the ability of Dynasmart-P to model partial equilibrium situations by inputting paths for individual drivers.

The same algorithm adopted by Dynasmart-P, the method of successive averages (MSA), was used to find dynamic equilibrium solutions. This algorithm routes drivers to a shortest path based on the congestion that exists in the network in the time slice in which the trips commences, similar to an option in Dynasmart-P. Dynasmart-P can also build forward-looking, "dynamic" paths, but this option was not needed for the tests later in this report.

These observations were made while creating the DTFM.

- Given the intensity of the calculations required for long-range ITS deployment planning, it is unreasonable to expect to perform simulations covering a time period in excess of 1 hour. The longest practical time slice to capture dynamic effects is 15 minutes, the length of time used in the Highway Capacity Manual for most calculations. Allowing an additional one hour of required "spin-up" time would suggest that a minimum of eight time slices would be required for any single run of the DTFM. Convergence of the equilibrium assignment algorithm in the DTFM is not any faster than convergence of a traditional travel forecasting model, so the DTFM should require at a minumum eight times as much computation. The amount of needed "spin-up" relates to the length of the longest trips in a city, so larger cities would need more time slices. Shorter time slices, in the range of 5 to 10 minutes, might be necessary to properly forecast the effects of minor incidents, so the number of time slices would be substantially larger for this case.
- The DTFM creates many separate output files for each time slice. Some of these files, such as link loads, may be easily aggregated for later inspection and analysis; but other files, such as signal timing and delays, cannot be easily aggregated. Consequently, there would likely be a greater reliance by planners on MOEs that pertain to the whole network, such as vehicle hours traveled, than detailed statistics about individual nodes and links.
- Everything that is calculated by a traditional travel forecasting model can be calculated by a DTFM, including the full range of select-link and select-zone analyses.
- It is possible to avoid having to provide separate trip tables for each time slice. In a DTFM it is possible to factor 24-hour "production-to-attraction" trip tables for several trip purposes into "origin-to-destination" vehicle trip tables for a single time slice. Since a 24-hour production-to-attraction trip table is created synthetically with a "gravity model" within the DTFM, the amount of trip data needed to run a DTFM is much smaller than the amount of data needed to run a stand-alone DTA algorithm.
- Computer storage requirements are somewhat increased over travel forecasting models, because of the additional reports for each time slice. However, disk drives on the newest computers are large enough to handle forecasts in large urban areas. Many of the largest scratch files, such as computed trip tables and shortest paths, do not need to be retained once the calculation for a time slice has been completed.
- Overall, a DTFM for ITS deployment planning is technically feasible.

Figure 10. Flow Diagram of a Possible Dynamic Travel Forecasting Model for Long-Range ITS Deployment Planning



Long-Range ITS Planning

The issue of long-range ITS planning is missing from all of the ITS plans reviewed earlier. Some of the plans listed strategies in categories of short-term, medium-term and long-term, but the methodologies used to do this categorization were unexplained.

Unlike strategic planning, long-range planning must recognize the need for a sequence of future scenarios and alternatives within those scenarios. Such a recognition implies the need to accurately forecast traffic volumes as well as performing a traffic simulation.

Scenarios and Alternatives

Scenarios

A scenario is a description of the community at future point in time, essentially independent of the transportation infrastructure that might exist at that time. A scenario would involve such data as population forecasts, employment forecasts, fuel prices, environmental controls, household structure and levels of technology. Sometimes scenarios would also include an allocation of activities, particularly population and various sectors of employment, to traffic analysis zones. In order to correctly identify staging, long-range ITS planning involves a time stream of scenarios, each one a consequence of its immediately prior scenario.

It is often recognized that scenarios cannot always be fully decoupled from the state of the transportation infrastructure. For example, the activity allocation step in Figure 9 of the example four-step model (QRS II) is contained within a feedback loop that takes into consideration levels of traffic congestion on the network.

A scenario would imply the existence of a certain amount of randomness in the environment of the traffic system.

Alternatives

An alternative is a state of the transportation infrastructure and associated policies at a given point in time. An ITS alternative makes sense only within the context of a scenario. It is well understood in the field of transportation planning that the set of alternatives should include the null alternative. For ITS planning the set of alternatives should also include the "conventional" alternative.

The null alternative is not necessarily a "do-nothing" alternative. The null alternative incorporates all low-cost actions that would be routinely applied to the traffic system to address a variety of problems.

As illustrated by IDAS, any given alternative can be extremely complex, involving many diverse elements at many locations.

Staging

Only a limited number of future years are considered for transportation plans, constrained by the "planning horizon" and by resources that can be devoted to the effort. Plans are sometimes prepared for equally spaced years (e.g, 5, 10, 15, 20, etc. from now) or for years that become farther apart as they get more distant (2, 5, 10, 20, etc. from now).

At its simplest, staging requires that ITS alternatives be developed and analyzed for many different future years. Each alternative is evaluated within the context of the current scenario and the best alternative is selected without regard to what may have been selected in previous years.

A more complex staging process may be required for good long-range ITS plans. This more complex staging recognizes that (1) earlier years have ITS and conventional infrastructure that is worth preserving and (2) travel patterns may have been altered because of alternatives selected in an earlier year. Figure 11 shows how this more complex staging might be implemented using existing software products such as IDAS or QRS II. In this flow diagram the only computerized step is the traffic simulation. The generation of the many possible alternatives in each forecast year would be performed using planning and engineering judgment. The flow diagram also shows that the generation of alternatives in any forecast year is constrained by decisions made in earlier years. In this manner, the value of assets already deployed is conserved.

Figure 11. ITS Staging with Available Software Tools Involving Professional Judgment to Select Alternatives

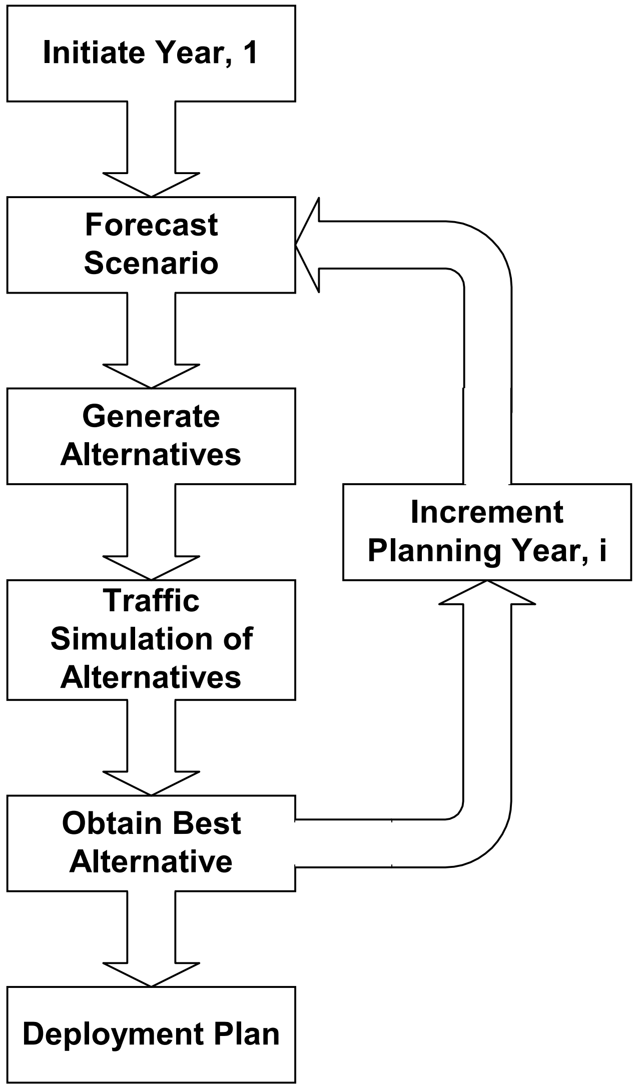


Figure 12 shows how this process might be automated with specialized software. This figure recognizes that the design of an alternative is a rather complicated combinatorial problem that, because of the number of elements involved, may easily exceed the abilities of planners and engineers using professional judgment. The flow diagram includes a loop where the best alternative is designed for the scenario by iterating many times through the "select alternative", "traffic simulation of alternative" and "evaluate alternative" steps.

Also included is a loop between a "stochastic environment" step and the travel forecasting model. The "stochastic environment" step creates a series of different traffic situations, such as incidents, that could have different impacts on MOEs. A true random process is not recommended because it would make it difficult to compare alternatives, and it may create deployment plans that are tailored too closely to the peculiarities of specific random situations.

Each traffic situation has an associated probability of occurrence, which can be used later to weight the results of the simulation containing that occurrence.

A very simple example of the deployment of variable message signs (part of strategy C) may help illustrate the process shown in Figure 12. Figure 13 shows a city with a single freeway. The city is considering deploying variable message signs. In year 5 of the plan, it has already been decided that variable messages signs will be deployed at the points marked by stars and in year 10 of the plan (the current year for this example) variable message signs could be deployed at points marked by circles. Removing the signs deployed in year 5 would be as waste of valuable assets, so the existence of the signs is grandfathered into the scenario for year 10. Given that there are 8 possible new sites, there are 8^2 or 256 possible alternatives, not including conventional alternatives, which would require a fair amount of work to evaluate.

Figure 12. ITS Staging Involving Combinatorial Optimization for the Best Strategy in Any Year

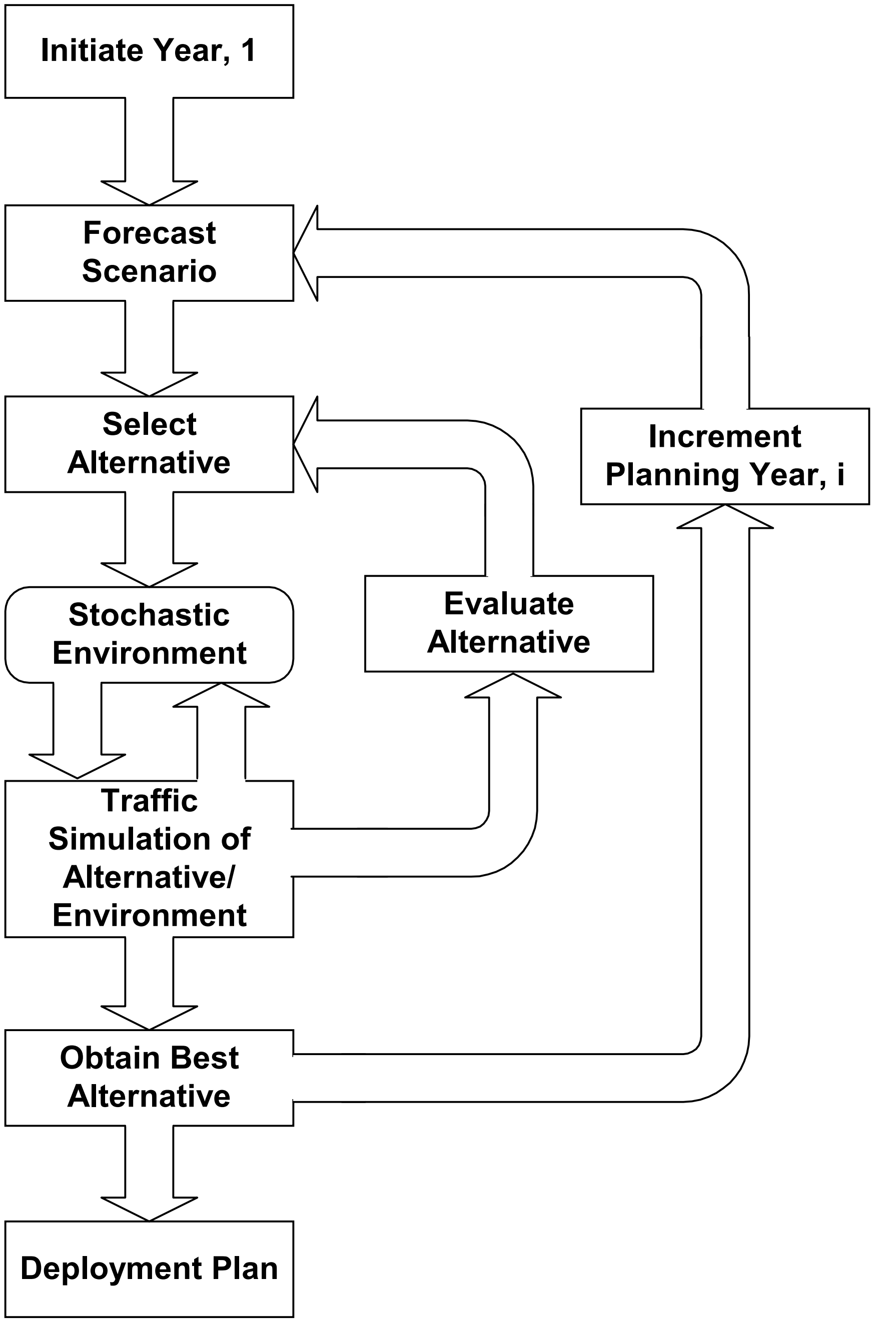
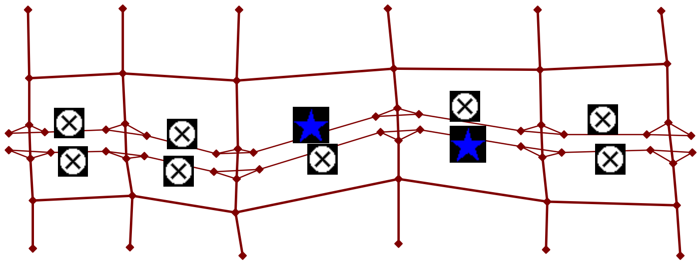


Figure 13. A Freeway Network Showing Variable Message Signs Deployed in a Given Year and Sites for Additional Signs



Should the flow diagram in Figure 12 be implemented in software, it would be possible to automatically consider all 256 alternatives or to consider only the most attractive alternatives, as chosen by a suitable combinatorial optimization algorithm. In the worst case, the inner loop of Figure 12 would need to be completed 256 times. It should be recognized that the number of alternatives could decline rapidly for later years as sites are used up and are dropped from further consideration.

Considering the size of our urban traffic networks and the large number of possible ITS elements that can be deployed, an exhaustive evaluation of every possible alternative, even with the fastest computers available today, would be impossible. However, combinatorial search algorithms exist (see Reeves, 1993) that can quickly eliminate clearly bad alternatives from consideration and improve good ones to become better or perhaps optimal.

Theoretically, it is also possible to optimize the complete deployment plan by finding the best combination of alternatives throughout all the planning years. In the freeway variable message sign example it might be desirable to move or destroy signs deployed in a previous year to better accommodate new sites for signs. If moving or destroying is allowed, then the alternative selection process balloons into a potentially gigantic combinatorial problem with N possible alternatives:

$$N = 2^{ET}$$

where E is the number of ITS elements that are possible and T is the number of years. If the example problem were limited to just 4 distinct years (e.g., years 5, 10, 15 and 20) and all 10 sign locations, then the number of possible alternatives is 1,099,511,627,776. Extreme simplifications would be required for this problem to be solved in a reasonable amount of computation time.

Multiple Criteria and Grandfathering

As stated earlier, criteria are measures of the attainment of goals and objectives. Almost all long-range transportation plans are based on multiple criteria such as travel time savings, safety, air pollution emissions, capital costs and maintenance costs. The method by which multiple decision criteria within an optimization framework is handled is critical to the results.

Many optimization models minimize a single objective function that consists of or imbeds a linear combination of various criteria. A benefit-cost analysis, such as implemented in IDAS, is an example of a technique that embeds a linear function by summing all of the project benefits in monetary units. Although very convenient, an objective function of this nature may create selected alternatives that are inconsistent with the goals of the ITS plan.

Sometimes certain criteria are removed from the objective function and handled as constraints. For example, a constraint may be placed on the optimization to assure that air pollutant emissions do not increase. Grandfathering is also a form of a constraint by specifying that certain ITS elements must be selected in a given year. Because grandfathering creates an unalterable deployment of ITS elements for all years in the future, it fully preserves the investment in assets at the expense of a suboptimal solution with respect to other criteria.

Stakeholder Input

Stakeholder input assures that the alternative is technically feasible, but getting adequate stakeholder input during an automated choice process would be very difficult. Stakeholder input can occur only at the beginning (proactive) or end (reactive) of the process.

Proactive stakeholder input at the beginning of the process could be used to establish a set of constraints that will narrow the number of solutions to those that make the most sense technically. For example, a stakeholder might determine that it is inefficient to have too close a spacing on variable message signs, thus eliminating all alternatives where variable messages signs are on adjacent links in the same direction of travel. Proactive stakeholder input has the advantage of automatically establishing the technical feasibility of any alternative, but it requires a means of translating expert opinion into a set of mathematical relations.

Reactive stakeholder input at the end of the process would require a subjective evaluation of a complex, multiyear deployment plan. While it is possible that stakeholders could fix a perceived problem with the plan, it is more likely that any serious problems would require that the plan be rejected.

Essential proactive stakeholder input includes:

- Cost data on deployment alternatives, both fixed and variable, and projections as to how costs may decline with time;
- The degree to which grandfathering needs to be respected;
- Estimated availability dates for technologies;
- The life span of candidate technologies and equipment and their depreciation rates;
- Constraints on deployment;
- Logical arrangements of elements;
- Synergies between various elements;
- Performance characteristics of elements; and
- Opinions as to the best way to represent the performance of an element in software.

Application of Stochastics: Recognition of Random Situations

The standard method of benefit-cost analysis to dealing with random situations is to find the "expected benefit" by weighting the benefits of a deployment with a random situation by the probability of that situation occurring. Thus, if b_i is the benefit of a deployment under situation *i*, then total benefits *B*, can be found from:

$$B = \sum_i b_i p_i$$

where p_i is the probability of situation *i* and the sum over all p_i is 1. It is unreasonable to include every possible situation, so judgment must be exercised to include the highest probability situations and any low probability situation with abnormally large benefits. Similar reasoning applies to costs of random situations.

Costs and Technologies

It is well known that the costs of communication and information technologies decline with time. Sometimes technologies that are infeasible due to cost in an early year become cost effective in later years. Thus, it is may be necessary to make costs of deployment a function of time, which can improve the cost effectiveness of certain ITS options in the later years of the plan.

It is possible that unanticipated new technologies may become available in the distant future. It is not possible to include such technologies into ITS deployment planning without a good deal of speculation. New technologies that simply replace existing technologies while performing the same function can be easily considered (such as digital wireless replacing analog wireless) in the plan.

Application of the Concepts with Potential Software

Introduction of the Problem

Given the complexity of some of the concepts presented earlier, it is best to illustrate them with a small network and a single ITS strategy that is well understood. The purpose of this section is to illustrate how some of the steps in the process can be implemented in software without necessarily producing an analysis at the same level of complexity that would be required in a real planning effort. This example designs a freeway incident management program over a 15-year period for the Utown test network. Although there are many aspects of incident management, the example problem will emphasize those aspects that improve the emergency responsiveness, such as service patrols and accident investigation sites.

Utown is a frequently used, hypothetical network for testing travel forecasting models. The version of the Utown network adopted here (see Figure 14) has an modest freeway system, many signal-controlled intersections and several stop-controlled intersections.

The dynamic travel forecasting model is the experimental version of QRS II, as described earlier. Delay at traffic-controlled intersections is calculated using operational analysis procedures from the 1997 Highway Capacity Manual (Horowitz and Granato, 2000), and delay along uninterrupted facilities, such as freeway mainline links, are calculated with the BPR curve as specified in NCHRP Report #365 (Martin and McGuckin, 1998).

The problem is to select the optimal combination of links to include in the incident management program that achieves the greatest net benefit for each of 4 forecast years. Utown is forecasted to grow by 10% every five years. Figure 14 also identifies the 12 freeway links that are assumed to have a chance of an incident and could be subject to an incident management program. The numbers next to each link represent the internal link numbers within the travel forecasting model and will be used for reference in this discussion.

The travel forecast covers a time period of one hour, divided into four 15-minute time slices. A spin-up period of 1 hour is appended to the beginning of the simulation. Thus, there are a total of 8 slices. Only slices 5 to 8 are used for evaluating the benefits of an alternative. Slice 1 occurs at 4:00 to 4:15 pm and slice 8 occurs at 5:45 to 6:00 pm. Time of day and direction of travel information for each of three trip purposes (home-based work, home-based nonwork, and nonhome based) was adapted from NCHRP Report #365, interpolated to 15-minute time slices from the hourly data found in that report.

As is common for this type of analysis, an incident is defined as a reduction in capacity for a set of time slices. An incident management program has the effect of reducing the duration of an incident. In order to assess the effects of different incident management alternatives, each link could have one or many random incidents. For simplicity in the case study, one incident was defined for each link and a probability was associated with each incident. Table 15 lists the links by number in Figure 14, the capacity reduction, the start slice, end slice with and without management, the probability of an incident occurring in a single hour of time and the cost per link of providing the incident management.

Figure 14. The Utown Network Showing Internal Link Numbers

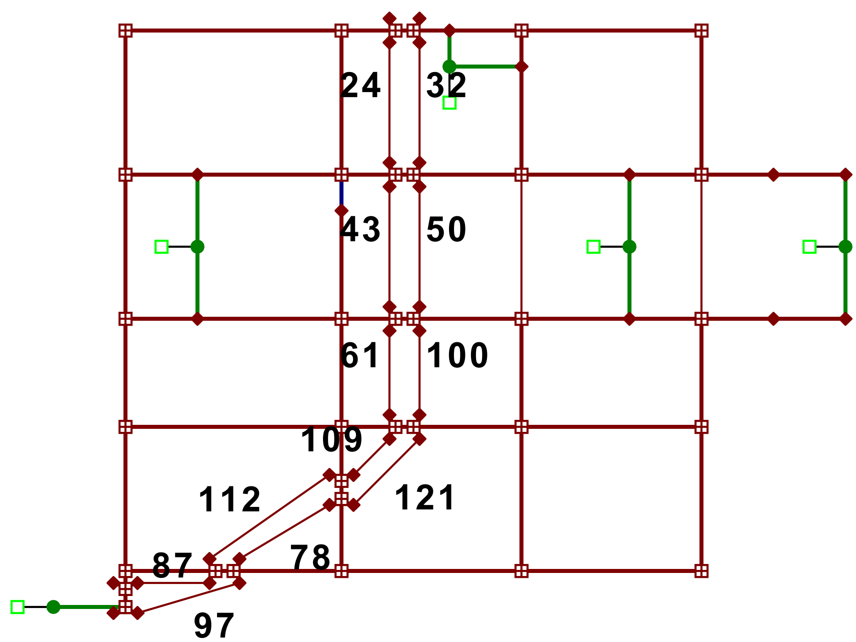


Table 15. Definition of a Possible Incident for Each Freeway Link in Utown

Incident Link	Start Slice	End Slice without Management	End Slice with Management	Capacity Reduction	Probability of Occurrence	Cost of Providing Management
24	5	6	5	4200	0.02	15
32	6	8	7	4200	0.02	15
43	5	8	7	4500	0.02	15
50	6	7	6	4200	0.02	15
61	6	8	7	4500	0.02	15
78	4	6	5	4200	0.02	15
87	5	7	6	2400	0.03	15
97	6	8	7	4200	0.03	15
100	4	7	6	4200	0.03	15
109	6	8	7	4200	0.03	15
112	5	6	5	4200	0.03	15
121	7	8	7	4200	0.03	15

Net benefit is defined as the value of time savings (above no incident management) minus the cost of providing the management.

Stakeholder Input

The following stakeholder input is typical for incident management programs.

- There are both fixed and variable costs associated with providing incident management. Fixed costs are related to providing the technological and institutional infrastructure necessary to operate the program.
- Service patrols cost approximately $60 per hour and each vehicle, if fully dedicated to the program, can cover about 10 miles of freeway (both directions). Thus, it is most efficient to work in contiguous segments totaling about 10 miles each where both sides of the freeway are covered by the same vehicle.
- Decreasing the variability in travel times is important.
- The technology of service patrols will remain viable until the planning horizon.
- A 15-minute reduction in the length of an incident is a reasonable goal.
- The average value of time for the drivers and passengers of a vehicle is $10 per hour.
- The fixed cost of operating the incident management plan is $50 per hour.
- Major costs revolve around personnel, so the cost of operating an incident management program will not decline appreciably in future years.

Optimization Problem and Objective Function

In any year, the net benefit of an incident management plan should be maximized. There are a number of incidents (designated by index *i*), randomly selected that occur on many links in the network. Let x_i be a Boolean variable that has a value of 1 when incident *i* is managed and a value of 0 when incident *i* is not managed. The expected value of total time savings, *s*, by implementing an incident management plan is:

$$s = \sum_{i=0}^{n} p_i v_i - \sum_{i=0}^{n} p_i (1 - x_i) v_i - \sum_{i=0}^{n} p_i x_i v_i^*$$

where v_i is the network vehicle hours of travel when an incident *i* is not managed, v_i^* is the network vehicle hours of travel when an incident *i* is managed, *n* is the number of incidents, and p_i is the probability of an incident. This equation assumes that the probability of an incident on two or more links simultaneously is negligible and that incidents are independent.

When *i* is 0, there is no incident, which is the usual case in this example and has the greatest value of p_i. Therefore, $v_0 = v_0^*$, and the value of x_0 is irrelevant. The first term of this equation is the vehicle hours of travel when there is no incident management plan at all and the second two terms are the vehicle hours of travel when an incident plan is implemented. This equation for time savings can be simplified by combining the first two terms.

The total benefits *b* of an incident management plan may be approximated as:

$$b = sm - x_i c_i - f$$

where m is the monetary value of time, c_i is the cost of managing incident *i* and *f* is the fixed cost of the incident management plan. In the Utown example, there is one possible incident per link, so *i* also denotes a particular link.

The objective is to maximize *b*, subject to a reasonable set of constraints on the selection of the x_i's. In the Utown example, the only constraint on the optimization is the requirement that managed links must be contiguous. Grandfathering is not enforced in this example, because service patrols are easily redeployed to different locations and much of the value associated with institutional and technological infrastructure can be recovered.

Each calculation of v_i and v_i^* requires a time-consuming traffic forecast for each planning year. However, only 2*n* – 1 traffic forecasts must be run for each planning year, which would likely be far smaller than the number of possible alternatives in full-sized networks.

The Utown example is simple enough so that all possible alternatives can be generated by hand. An alternative consists of a contiguous set of segments – a segment consisting of northbound and southbound links at the same location. There are 21 possible alternatives for the Utown network. For a full-sized network, it would be helpful to have a computer generate alternatives automatically.

The Solution

In order to obtain precise forecasts of vehicle hours of travel, the Utown network was run through 200 iterations of MSA. This many iterations gives a precision better than 2 vehicle hours. Table 16 shows the VHT forecasts for the third planning year, 10 years hence, for each incident, both unmanaged and managed.

Table 16. Vehicle Hours Traveled for Managed and Unmanaged Incidents in the Third Planning Year

Incident Link	Unmanaged VHT	Managed VHT
No Incident	3520	3520
24	3535	3527
32	3522	3523
43	3535	3534
50	3520	3520
61	7904	4905
78	3533	3529
87	3802	3668
97	3524	3528
100	3519	3517
109	4369	4101
112	5031	5037
121	3520	3525

It is evident that there were significant decreases in VHT only for incidents on links 61, 87 and 109, which are among the most congested links. Most links did not show a significant decrease and three links (97, 112 and 121) actually showed significant increases. Such anomalous results are common in these types of simulations because of Braess's paradox and the possibility of multiple equilibrium solutions. Braess's paradox states that improvements in an equilibrium traffic network do not always result in lowered VHT. Multiple equilibrium solutions can affect highly congested networks with traffic signals so that two simulations of essentially the same network can often result in two different solutions (Meneguzzer, 1997). Usually the differences are slight and ignorable, but care must be taken to assure that such results do not distort the findings.

It is evident by looking at Table 16 that only incident plans that efficiently cover link 61 have a chance of being cost effective. The 3000 vehicle hours of time saving that would result from managing this incident occurs just 2% of the time, for an expected daily savings of about 60 vehicle hours. The most compact scheme that does this would involve links 61 and 100 for an operating cost of $80 per hour. The expected monetary value of time saving for this scheme is $600.

The optimal scheme in terms of net benefit also covers links 87 and 109, as expected. This scheme (covering links 61, 87, 97, 100, 109 and 121) has a positive net benefit of $578 or a benefit cost ratio of about 5.1 to 1. The benefits of incident management in each of the planning years are shown in Table 17.

Table 17. Optimal Incident Management Plans in Four Planning Years

Planning Year	Optimal Plan	Net Benefit
Now	none	$0
5 Years from Now	none	$0
10 Years from Now	61, 87, 97, 100, 109, 121	$578
15 Years from Now	61, 87, 97, 100, 109, 121	$1590

Note that the 15-year optimal plan is the same as the 10-year plan, but the net benefits are considerably higher. Not evident in Table 17 are the optimal plans for years 1 and 2, neither of which had positive net benefits. In both years the optimal plan involved managing links 61 and 100. In year 1, this plan saved less than 2 vehicle-hours per day on average and in year 2 this plan saved less than 3 vehicle-hours. It is readily apparent that the value of incident management increases rapidly with increases in the amount of traffic.

Observations

The need for many equilibrium iterations relates to the severe capacity reductions on some links caused by the incidents. 200 equilibrium iterations are unusually large. The optimization required approximately 10 hours of computation running in the background of a 1.7 gigahertz Pentium-4 computer. A trial with 400 equilibrium iterations gave essentially the same answers. A real network would likely require just a small fraction of this number of equilibrium iterations, although the computation time for each equilibrium iteration would be greater.

As expected, some of the incidents created very serious congestion on the surface arterials of the network. The serious congestion affected the model's ability to find unique equilibrium solutions, as the mathematical conditions for uniqueness are usually violated when serious congestion occurs. This issue is likely to be a problem in all applications of this methodology, as incidents (particularly planned incidents) tend to cause congestion on local arterials as well as on freeways. It may be possible to reduce the possibility of multiple equilibrium solutions by choosing a fixed timing for the signals; the simulation reported here allowed green times and phasing to be traffic responsive. The worst case situation of multiple equilibrium solutions or Braess's paradox causing an increase in VHT when a link was managed occurred in the fourth planning year. The increase was 10 vehicle hours, representing a maximum error in the estimate of net benefit of $3.

Application of the Concepts with Existing Software

IDAS was used to test several ITS strategies on the same full-sized Cedar Rapids (Iowa) highway network that was used by Horowitz and Granato (2000) for signal deployment. The six IDAS strategies, relating to those identified earlier as being particularly relevant to the Midwest region, are:

1. Centrally controlled ramp metering, deployed to all on-ramps
2. Actuated corridor signal coordination, deployed to all arterial links near and crossing freeways
3. Incident detection/response, deployed on all freeway links

4. Freeway dynamic message signs, deployed at either 4, 10 or 19 locations as determined by using engineering judgment
5. Telephone-based traveler information system, deployed to the whole system
6. Web/Internet traveler information system, deployed to the whole system

The Cedar Rapids network shown in Figure 15 includes over 600 traffic controlled intersections that are modeled in accordance with Highway Capacity Manual procedures when simulated within QRS II. About 230 of these intersections are signalized, about 80 intersections are all-way stops and the remaining intersections are some-way stops. Overall the network contains almost 2600 nodes, 3800 links (one-way or two-way) including zonal access points, 482 zones, and 55 external stations. The network contained all existing arterial and freeway facilities and all committed facilities. The base year for this network is 1994. This network was calibrated and validated in Cedar Rapids to standards that more than satisfy planning practice for accuracy in the base-year forecast.

IDAS required a network and a vehicular origin-destination table. The network was adapted from QRS II by removing all traffic controls (as they are not recognized by IDAS) and by halving all capacity values on arterials to better match IDAS's BPR curves for delay on that type of link. Turn restrictions were transferred to IDAS manually, and turn penalties were ignored because their values depend on the existence of traffic controls in the network. The base-year origin destination table for the afternoon peak hour was created by running the original 1994 network in QRS II through 11 MSA averages for elastic demand, equilibrium traffic assignment, as illustrated in Figure 7. The origin-destination table was equilibrium-averaged and included trips between all zones and all external stations. The conversion of data between QRS II and IDAS was far from automatic; custom software was needed to perform the conversion. No attempt was made to recalibrate the network once it had been transferred to IDAS, although such a step would seem prudent for real planning applications, considering the substantial differences between software packages.

Except for ITS strategies, the network was held constant through all planning years, and the origin-destination table was inflated by 14% per planning year (at 5-year increments) within IDAS, consistent with population forecasts for Cedar Rapids. It would have been possible to create all future-year origin-destination tables within QRS II for the sake of slightly greater conformity with local demographic forecasts, but this extra step was not considered important to the understanding of the nature of a multi-year simulation process.

While implementing strategies in successive years, grandfathering was enforced across all years. For example, the selected strategies in planning year 4 encompassed the strategies selected in planning year 3.

A much simpler concept for alternatives is allowed for IDAS than can be evaluated with the DTFM framework as described earlier. Using engineering judgment, twelve alternatives in the first planning year were enumerated to reasonably cover the more promising combinations of the six strategies. Because of the use of benefit-cost analysis the comparison to the null alternative is automatically built into the analysis. These alternatives and their benefit-cost ratios for the first planning year are listed in Table 18. Only Alternative H1, consisting of Strategy 6 (Web/Internet ATIS), had a benefit-cost ratio greater than 1.

Figure 15. Cedar Rapids Network

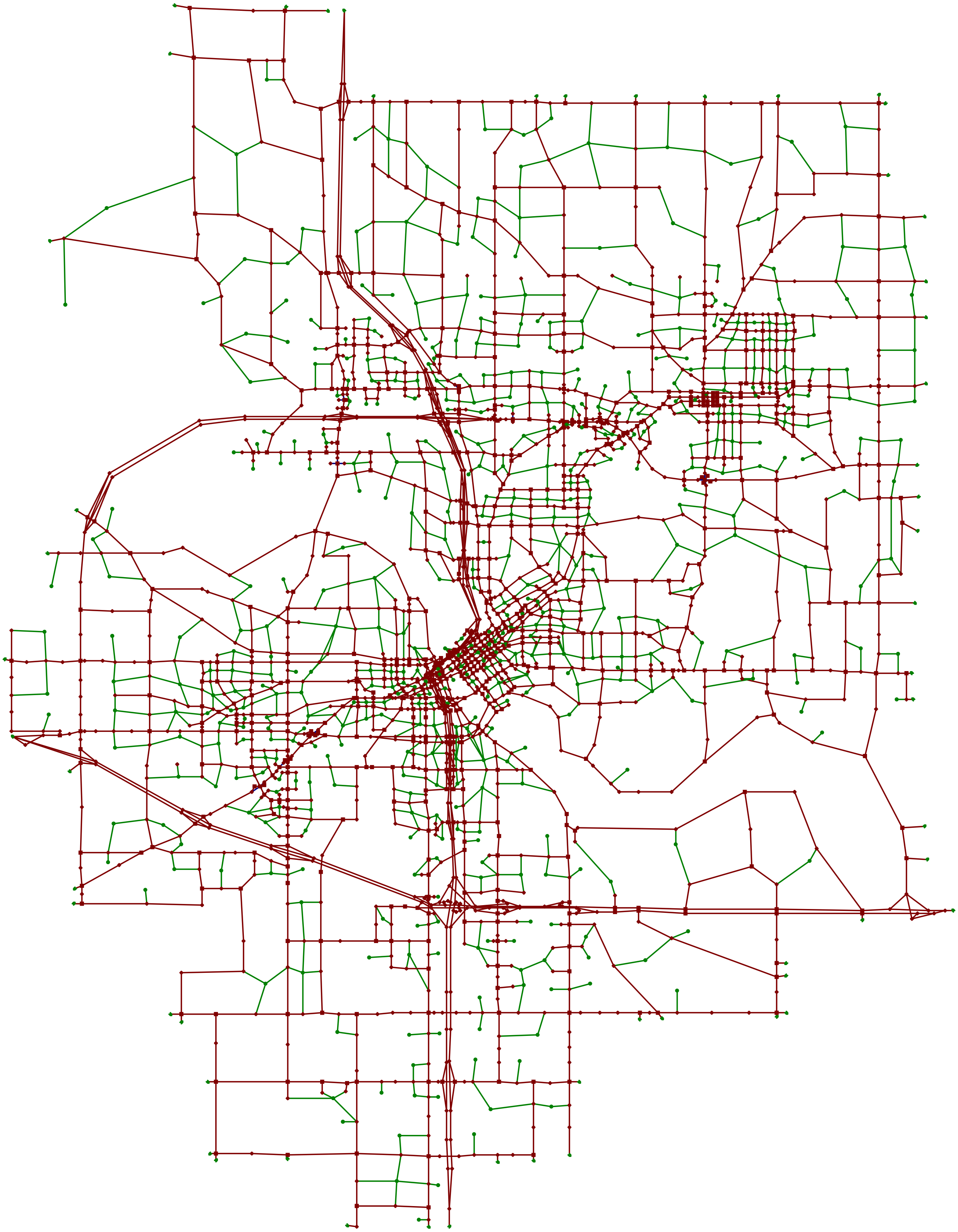


Table 18. Year 1 Alternatives and Benefit-Cost Ratios from IDAS

Alternative	Benefit Cost Ratio
A1. Strategy 1	0.49
B1. Strategies 1+2	0.54
C1. Strategy 3	0.82
D1. Strategy 4a (4 VMSs)	0.22
E1. Strategy 4b (10 VMSs)	0.20
F1. Strategy 4c (19 VMSs)	0.24
G1. Strategy 5	0.88
H1. Strategy 6	2.03
I1. Strategies 5+6	0.15
J1 Strategies 1+2+3	0.64
K1. Strategies 1+2+3+4b	0.59
L1. Strategies 1+2+3+4b+5+6	0.48

It is observed that IDAS is not free from anomalous results. For example, the benefit cost ratio of Alternative I1 is illogically much lower than either the benefit-cost ratios of Alternatives G1 and H1.

A new set of alternatives for the second planning year was created that grandfathered Strategy 6 into all alternatives. By including Strategy 6 in all alternatives, one of the previous alternatives became redundant and was omitted. Also omitted was Alternative H2, which is moot. The benefits-cost ratios for 10 remaining alternatives in the second planning year are shown on Table 19. This same process was continued through the third and fourth planning years on Tables 20 and 21.

Table 19. Year 2 Alternatives and Benefit-Cost Ratios from IDAS

Alternative	Benefit Cost Ratio
A2. Strategy 1+6	0.46
B2. Strategies 1+2+6	0.44
C2. Strategy 3+6	0.74
D2. Strategy 4a (4 VMSs)+6	0.08
E2. Strategy 4b (10 VMSs)+6	0.17
F2. Strategy 4c (19 VMSs)+6	0.11
G2. Strategy 5+6	1.56
H2. Omitted	-----
I2. Omitted	-----
J2. Strategies 1+2+3+6	0.68
K2. Strategies 1+2+3+4b+6	0.74
L2. Strategies 1+2+3+4b+5+6	0.73

Table 20. Year 3 Alternatives and Benefit-Cost Ratios from IDAS

Alternative	Benefit Cost Ratio
A3. Strategy 1+5+6	1.24
B3. Strategies 1+2+5+6	1.16
C3. Strategies 3+5+6	1.22
D3. Strategies 4a (4 VMSs)+5+6	3.25
E3. Strategies 4b (10 VMSs)+5+6	2.90
F3. Strategies 4c (19 VMSs)+5+6	2.54
G3. Omitted	-----
H3. Omitted	-----
I3. Omitted	-----
J3. Strategies 1+2+3+5+6	1.01
K3. Strategies 1+2+3+4b+5+6	0.99
L3. Omitted	-----

Table 21. Year 4 Alternatives and Benefit-Cost Ratios from IDAS

Alternative	Benefit Cost Ratio
A4. Strategies 1+4a+5+6	2.24
B4. Strategies 1+2+4a+5+6	0.91
C4. Strategies 3+4a+5+6	2.37
D4. Omitted	-----
E4. Strategies 4b (10 VMSs)+5+6	9.67
F4. Strategies 4c (19 VMSs)+5+6	8.54
G4. Omitted	-----
H4. Omitted	-----
I4. Omitted	-----
J4. Strategies 1+2+3+4a+5+6	1.41
K4. Strategies 1+2+3+4b+5+6	1.41
L4. Omitted	-----

Alternative G2 had the only benefit-cost ratio greater than 1 in the second planning year, so Strategy 5 was added to all subsequent alternatives. In the third planning year, Alternative D3 (consisting of strategies 4a, 5 and 6) was superior. Alternatives E3, F3 and K3 encompasses the strategies of Alternative D3 and their benefit-cost ratios were lower than D3. It is not possible to determine if any of the other alternatives would be superior, if enhanced by including Strategy 4a, without performing additional simulations. Thus, it seems reasonable to only grandfather Alternative D3 into the alternatives for planning year 4. In planning year 4, Alternatives D4, G4, H4, I4 and K4 were eliminated due to redundancy. Alternative E4, adding 6 more VMSs (for a total of 10), had the best benefit cost ratio. Alternatives F4 and K4 encompass the strategies of Alternative D4 but have lower benefit cost ratios. Similar to the previous year, the other alternatives cannot be assessed as being superior, if enhanced by including Strategy 4b, without performing additional simulations.

In summary, the multiyear deployment of ITS strategies is:

Planning Year 1: Strategy 6, Web/Internet ATIS
Planning Year 2. Strategy 6, Web/Internet ATIS + Strategy 5, Telephone ATIS
Planning Year 3. Strategy 6, Web/Internet ATIS + Strategy 5, Telephone ATIS + Strategy 4a, 4 VMSs
Planning Year 4. Strategy 6, Web/Internet ATIS + Strategy 5, Telephone ATIS + Strategy 4b, 10 VMSs

Discussion

The relationship between traffic growth and the deployment of ITS strategies over time is fairly clear in this example. Benefit cost-ratios for alternatives improve greatly with growth in traffic.

Engineering judgment was required to establish the alternatives, so it is unlikely that any of the alternatives are optimal for the network in any planning year. The lower benefit cost ratios might be able to be improved by trying different versions of the strategies within those alternatives.

Proactive stakeholder input is less essential with IDAS than with a DTFM, because of the inherent limitations of the software and its large database of ITS strategies, their benefits and their costs. Expert opinion is still necessary to ascertain which strategies can be readily combined into workable alternatives and to determine the configuration of each strategy.

A recalibration of the traffic network within IDAS would most likely be required when it is transferred from another software package that uses different methods of traffic assignment and delay.

A reliance on benefit-cost ratios for selecting alternatives may preclude the selection of an alternative that is costly, but has a large net benefit.

Grandfathering only resulted in the elimination of five alternatives by planning year 4.

Conclusions

There are many ITS strategies that have long-range deployment issues. Prominent examples of strategies that are relevant to the upper-Midwest US relate to incident (both random and planned) management, driver information and integrating traffic controls on freeways with those on arterials.

A clear distinction needs to be made between strategic ITS deployment planning and long-range deployment planning. Very little effort has been made to develop a consistent process even for strategic ITS deployment planning. However, it is possible to combine the best elements of several ITS planning studies to achieve a general process that will work well for most urban areas and states.

Long-range ITS deployment planning can be conducted using essentially the same process as strategic ITS planning, except that staging decisions become more explicit, stakeholder input is needed at different points in the process and different methods are needed to forecast the effects of ITS elements on future traffic conditions.

Primary difficulties in generating and evaluating ITS alternatives relate to the huge number of possible alternatives and the needs to consider prior year commitments, short-lived traffic phenomenon and random effects. All of these problems can be overcome, but specialized software is required, and the use of such software will require a large amount of computation time.

At present no software package can adequately evaluate long-range ITS deployments. The most promising software configuration for long-range ITS deployment planning would be a dynamic travel forecasting model (DTFM). By combining the best features of a dynamic traffic assignment (DTA) with the best features of a conventional travel forecasting model with traffic simulation, it is possible to create a simulation that does not require an unreasonable amount of input data and can rigorously address many ITS strategies. The need to conserve computation time suggests that macroscopic traffic simulation methods, such as those found in the Highway Capacity Manual, would be favored over microscopic or mesoscopic techniques. Simplistic delay relations for traffic controls, such as the BPR curve, should be avoided. An experimental version of a DTFM was shown to be capable of evaluating a time-staged incident management deployment for a small test city. The amount of computation time needed to evaluate one ITS strategy in a test network suggests that the slowness of the optimization/simulation is a major concern. The possibility of multiple equilibrium solutions also remains a concern.

When using simulations to evaluate ITS alternatives, it is essential that stakeholder input be solicited prior to specifying the simulation. Each ITS strategy is somewhat different in how it must be simulated, so the software must be written (or configured) to meet the evaluation needs of the strategy as stipulated by stakeholders. Stakeholder input may also be necessary after the simulations to assure that the generated alternatives are technically feasible.

The generation of alternatives is a combinatorial optimization problem where there can be a very large number of possible alternatives. Stakeholder input is critically important as it may have a constraining effect on the number of solutions, making the optimization more tractable. Grandfathering (including all previous ITS strategies into subsequent sets of strategies) has the effect of further constraining the number of possible alternatives, but grandfathering may not be appropriate for all strategies.

It is recommended that both an IDAS-like model and a DTFM be used to evaluate long-range ITS deployment strategies. An IDAS-like model can be used to incorporated stakeholder input into a screening process for workable alternatives. The DTFM can be used to refine and optimize those alternatives selected by an IDAS-like model.

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3. Intelligent Transportation Systems (ITS) Strategic Plan, Tennessee Department of Transportation, June 1998.
4. Strategic Deployment Plan, Dane County Incident Management Program, prepared by HNTB, August 1999.
5. Minnesota Guidestar Board of Directors' Statewide ITS Strategic Plan, 2000, Minnesota Department of Transportation, March 2000.
6. Spokane Regional ITS Implementation Plan, prepared by Transpo Group, IBI, and SRTMC staff, July 2000.
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9. A Methodology for Prioritizing Intelligent Transportation Systems (ITS) Projects in Southwestern Wisconsin, Wisconsin Department of Transportation, prepared by HNTB, February 16, 2001.
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11. Integrated ITS and Services Deployment Plan, Iowa DOT, July 2001.
12. Intelligent Transportation Systems Strategic Plan (draft), Colorado Department of Transportation, prepared by Dye Management Group, August 2001.
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14. ITS Intelligent Transportation Systems Strategic Deployment Plan, Pima Association of Governments (not dated).

On-line Sources of Information about Reviewed Software:

1. Dynasmart-P: www.dynamictrafficassignment.org

2. ITS Deployment Analysis System (IDAS): idas.camsys.com
3. Paramics: www.paramics-online.com
4. Quick Response System II (QRS II): www.execpc.com/~ajh

Other

National ITS Archetecture 3.0, CD-ROM, US Department of Transportation, November 1999.

Acknowledgments

The authors thank the MRUTC advisory committee (Jason Bittner, Lou Lambert, Rick Lilly, Mac Lister, Marthand Nookala, Jay Obenberger, Ron Vibbert and Ernie Wittwer) to this project and the staff of MRUTC, particularly Aileen Switzer, for their help in defining and completing this project. An earlier draft of this document was reviewed by Hani Mahmassani of the University of Texas at Austin (a developer of Dynasmart-P) and by Scott Aitken of Quadstone (a developer of Paramics), but the opinions expressed about software packages are those of the authors of this report. John Corbin of the Wisconsin Department of Transportation provided advice on stakeholder input for incident management.

Appendix

Appendix A. Summary of IDAS Tests

ITS Element	Tested	Affect on the network (IDAS Results on the Screen)		Could Affect Capacity	MOEs that Can be Affected:	
		Volume	Speed		Safety	Environment, Energy, Noise
Arterial Traffic Management Systems						
Isolated Traffic Actuated Signals	y	y	y	y	y	y
Preset Corridor Signal Coordination					y	y
Actuated Corridor Signal Coordination					y	y
Central Control Signal Coordination					y	y
Transit Vehicle Signal Priority					y	y
Emergency Vehicle Signal Priority	y	y	y	y	y	n
Freeway Management Systems						
Pre-set Ramp Metering					y	y
Traffic Actuated Ramp Metering	y	y	y	y	y	y
Centrally Controlled Ramp Metering					y	y
Fixed Route Transit – Automated Scheduling System						
Advanced Public Transit Systems					y	y
Fixed Route Transit – Automatic Vehicle Location	y	n	n	n	y	y
Fixed Route Transit – Combination Automated Scheduling System and Automatic Vehicle Location					y	y
Fixed Route Transit – Security Systems					y	y
Paratransit – Automated Scheduling System					y	y
Paratransit – Automatic Vehicle Location					y	y
Paratransit – Automated Scheduling System and Automatic Vehicle Location	y	y	n	n	y	y

ITS Element	Tested	Affect on the Network (IDAS Results on the Screen)		Could Affect the Capacity	MOEs that Can be Affected:	
		Volume	Speed		Safety	Environment, Energy, Noise
Incident Management Systems						
Incident Detection/Verification	y			a	y	y
Incident Response/Management					y	y
Incident Detection/Verification/Response/	y	n	n	a	y	y
Management combined					y	y
Electronic Payment Systems						
Electronic Transit Fare Payment	y	y	y	n	m	m
Basic Electronic Toll Collection					m	y
Railroad Grade Crossing Monitors	y	y	y	a	y	n
Emergency Management Services						
Emergency Vehicle Control Service					y (just for this type)	n
Emergency Vehicle AVL	y	n	n	a	y (just for this type)	n
In-Vehicle Mayday System					y	n
Regional Multimodal Traveler Information Systems						
Highway Advisory Radio	y	n	n	a	n	n
Freeway Dynamic Message Sign	y	n	n	a	n	n
Transit Dynamic Message Sign					n	n
Telephone-Based Traveler Information System					n	n
Web/Internet-Based Traveler Information System					n	n
Kiosk with Multimodal Traveler Information					n	n
Kiosk with Transit-only Traveler Information					n	n
Handheld Personal Device – Traveler Information Only					n	n
Handheld Personal Device – Traveler Information with Route Guidance					n	n
In-Vehicle – Traveler Information Only					n	n
In-Vehicle – Traveler Information with Route Guidance					n	n

ITS Element	Tested	Affect on the Network (IDAS Results on the Screen)		Could Affect the Capacity	MOEs that Can be Affected:	
		Volume	Speed		Safety	Environment, Energy, Noise
Commercial Vehicle Operations						
Electronic Screening	y	n	n	a	n	y
Weigh-in-Motion					y	n
Electronic Clearance – Credentials	y	n	n	a	y	n
Electronic Clearance – Safety Inspection					y	n
Electronic Screening/Clearance combined					y	y
Safety Information Exchange					y	n
On-board Safety Monitoring					y	y
Electronic Roadside Safety Inspection					y	n
Hazardous Materials Incident Response					y	y
Advanced Vehicle Control and Safety Systems						
Motorist Warning – Ramp Rollover					y	n
Motorist Warning – Downhill Speed					y	n
Longitudinal Collision Avoidance	y	y	y	y	y	y
Lateral Collision Avoidance					y	n
Intersection Collision Avoidance					y	n
Vision Enhancement for Crashes					y	n
Safety Readiness					y	n

Volume (y-n)	Running the program changed or not in the network on the screen
Speed (y-n)	Running the program changed or not in the network on the screen
Safety (y)	IDAS in general calculates accidents including fatalities, injuries, and property damage only (PDO) for the control alternative and ITS option, network-wide. The calculation is based on changes in VMT, speed, vehicle type and facility type.
Environment (y)	IDAS in general calculates emissions including all types of pollutants, and fuel consumption for control alternative and ITS option, network-wide. The calculation is based on changes in VMT, speed, cold starts, vehicle type and facility type.
Safety (n)	No statistically significant safety impacts have been identified for this ITS component MOEs unaffected
Environment (n)	No statistically significant environmental impacts have been identified for this ITS component.
m	Is not anticipated to have a significant impact. However, there might be slight impacts that IDAS will calculate
Capacity (a)	Ambiguous

Appendix B: Dynasmart-P Data Requirements

Data Required for the Network

<u>Node Data</u>: Node number (traffic simulation)
Total number of nodes (traffic simulation)
The coordinates (graphical representation)

<u>Link Data</u>: Total Number of Links (traffic simulation)
Saturation Flow (traffic simulation)
Free flow speed (traffic simulation)
Link horizontal alignment (graphical representation)
Link type (graphical representation)
Link name (graphical representation)

<u>Movement data</u>: Allowed movements from all links for traffic simulation.

Input Files

Five different input files are required to represent the network. For the graphical representation in GUI xy.dat, linkxy.dat and linkname.dat are needed and also optional. For the traffic simulation the network.dat and the movement.dat are required.

xy.dat

This input file contains the coordinates of the nodes.
The data required in this file is:
Node Number
X (X-axis coordinate)
Y (Y-axis coordinate)

linkxy.dat

This file contains the horizontal alignment of the links.
The data required in this file is:
Link upstream node (Link starting node)
Link downstream node (Link ending node)
Number of link-associated feature points (Are used to show the curve feature of links)
Coordinate on the x-axis of the 1st feature point
Coordinate on the y-axis of the 1st feature point

Linkname.dat

This file describes the link names used by the GUI
The data required in this file is:

Link upstream node (Link starting node)
Link downstream node (Link ending node)
Street name

Network.dat

This input file includes zoning, nodes numbering and link characteristics.
The data required in this file is:

Basic Data:

- Number of zones in the network
- Number of nodes in the network
- Number of links in the network
- Number of shortest paths to be calculated for each O-D pair
- Aggregation zone flag.

Node Data:

- Node number
- Zone number that the node belongs to

Link Data:

- Upstream node of link (starting node).
- Downstream node of link (ending node).
- Left turn bay
- Length of the link
- Number of lanes
- Free flow speed
- Saturation flow rate
- Link identification.
  - 1: freeway (fully-controlled access highways)
  - 2: freeway segment with detector
  - 3: on ramp
  - 4: off ramp
  - 5: arterial
  - 6: HOV/HOT lane
  - 7: highway (partially-controlled access highway)

Movement.dat

This input file includes geometrically available movements associated with a given link.

The data required in this file is:

Upstream node
Downstream Node
Left turn node number that a left turn movement leads to

Straight turn node number that a straight movement leads to
Right turn node number that a right movement leads to
Other movement 1
Other movement 2

Traffic Control

Dynasmart-P deals with intersections with no control, stop and yield signs, and pre-timed and actuated signals.

Control.dat

This file represents the control of each intersection.
The requirements are:

- Number of signal timing plans
- Start time of signal timing plan
- Node Data
  - Node number
  - Control type.
    - 1: no control
    - 2: yield sign
    - 3: stop sign
    - 4: pre-timed control
    - 5: actuated signal control
  - Number of phases
  - Cycle length
- Phasing data
  - Node number
  - Phase number
  - Offset (pre-timed), or maximum green time (actuated) for phase I
  - Green time (pre-timed), or minimum green time (actuated) for phase I
  - Amber time for this phase
  - Number of inbound links in this phase
  - Upstream nodes of the inbound links
- Phasing movements
  - Upstream node of the inbound link
  - Downstream node of the inbound link
  - Phase number
  - Number of movements allowed for the inbound link during this phase.
  - Associated downstream nodes that are reached from the inbound link for allowed movements.

A leftcap.dat file exists in Dynasmart for the left turn capacity of the link.

Trip Tables

Dynasmart-P deals with two different methods. Origin-Destination (OD) matrices among origin-destination zones at different demand time slices is the first method, and the other one is to specify the characteristics of all vehicles and their corresponding travel plans.

For the representation Dynasmart uses a zone data file, demand file, origin file and a destination file for the first method, and a vehicle file and a path file for the second method.

Zone.dat

The coordinates of the feature points on the boundaries of the zone are contained in this file.
The data required is:

- Total Number of feature points
- Number of zone
- Feature point number
- The x-coordinate of feature point
- The y-coordinate of feature point
- Zone number
- Number of feature points needed to define the boundary
- List of feature points that define the boundary

Demand.dat

This file is used to load the demand using a time dependent OD matix.

Data required:

- Number of loading slices (Number of OD matrices)
- Demand multiplication factor. (To control the uniform increase or decrease of the overall network loading level based on the OD matrix record type)
- Starting time of each loading slice
- Entries of O-D matrix. The general structure for the file is as follows:
  - [OD time1]
  - [OD time2] …
  - Within each [OD time] matrix, Row for each origin and column for each destination

Origin.dat

Dynasmart doesn't use centroids as a generation point. In Dynasmart the vehicles are generated from links. Generation links are specified in this file. (In the documentation is written that the user should not include freeway links as a generation link.)

Data required:

- Zone number

Number of generation links in zone
Loading mode. (0 default loading modes weights or 1 user specified loading weights)
Upstream node of generation link
Downstream node of generation link
Loading weights of generation links (is used is step 3 is 1)

Destination.dat

This file is used by Dynasmart to specify the destination nodes.

Data required:
Zone number
Number of destinations in zone
Destination Node number

Superzone.dat

This file is used to aggregate zones in o a single super zone. A centroid is created internally in Dynasmart. (optional file)

Data Required:
Total number of aggregated zones
List of original zones
Superzone number that the original zone mapps to

Vehicle.dat

This file is used to specify the vehicles characteristics and their corresponding travel plan.

Data Required:
Number of vehicles to be loaded
Maximum number of destinations in the vehicle path
Optional description of the data
Header for each field
Vehicle identification number
The upstream node of the generation link
The downstream node of the generation link
Starting time of vehicle
User class
Vehicle type
Vehicle occupancy
Number of nodes in the path
Number of destinations (stop) along the path
En route information indicator (available or not)

Indifference band (minutes) for switching
Response percentage
The zone number of the destination
The activity duration (min) at the destination

Path.dat

This file is used to specify the itinerary of each vehicle in the vehicle.dat input file.

Data required:
For each vehicle specify the nodes in the vehicle path starting by the origin.

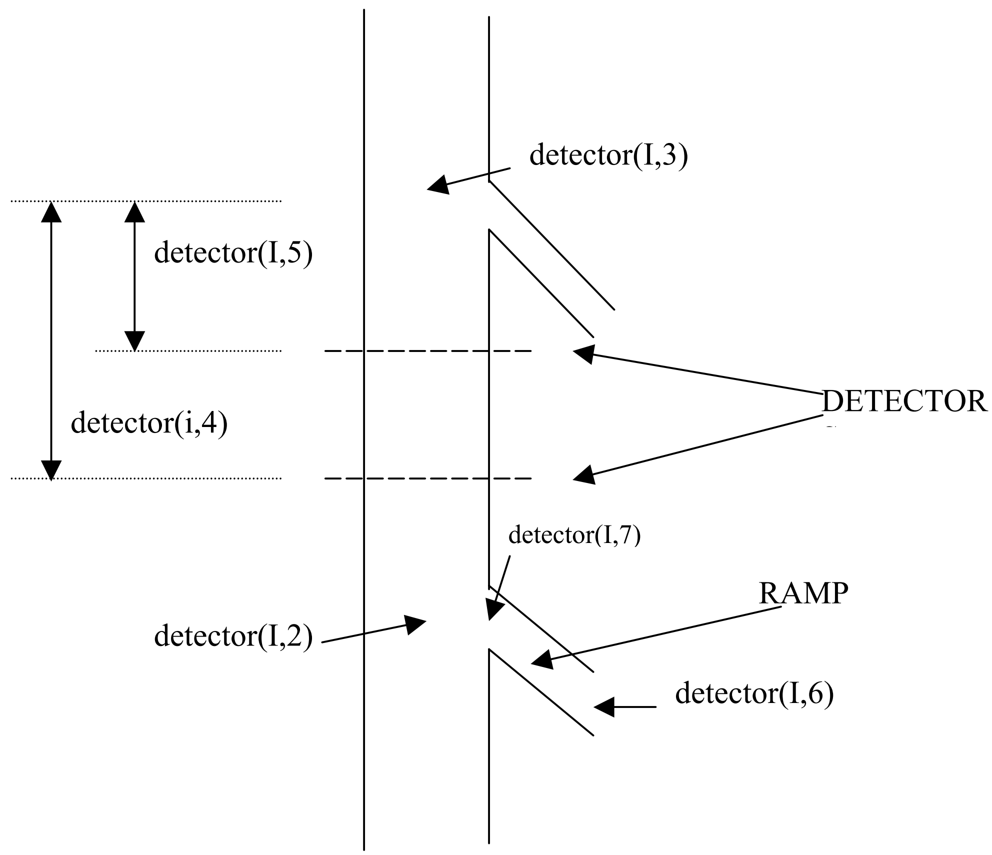
Ramp Control Data (ramp.dat)

This file contains ramp metering configurations.

Table B.1. Description of the Input File ramp.dat

Record Type	Field	Format	Field Width	Description
Number of ramps	DEC_NUM	Integer	6	Number for ramp meters.
	NRATE	Integer	6	The frequency at which the simulator check the start and the end of the ramp metering (in minutes)
Ramp data	DETECTOR(I,1)	Integer	6	Detector ID number.
	DETECTOR(I,2)	Integer	6	Upstream node of the downstream link of the metered ramp.
	DETECTOR(I,3)	Integer	6	Downstream node of the downstream link of the metered ramp.
	DETECTOR(I,4)	Integer	6	Position of the first detector on downstream link (in feet) measured from the downstream node of that link.
	DETECTOR(I,5)	Integer	6	Position of the second detector on the downstream link (in feet) measured from the downstream node of that link.
	DETECTOR(I,6)	Integer	6	Upstream node of the metered ramp.
	DETECTOR(I,7)	Integer	6	Downstream node of the metered ramp.
	RAMP_PAR(I,1)	Float	7(3)	Constant used in calculating the flow rate of the ramp (default=0.32).
	RAMP_PAR(I,2)	Float	6(2)	Constant used in calculating the flow rate of the ramp (default=20.0).
	RAMP_PAR(I,3)	Float	6(2)	Saturation flow rate on the ramp veh/sec/lane (default=0.5).
Start/end Time for ramp metering	RAMP_START(I)	Float	8(2)	The starting time for the metering at ramp I.
	RAMP_END(I)	Float	8(2)	The ending time for the metering at ramp I.

Figure B.1: Ramp Metering Input Description



The following shows the general format for this file.

```
     8     1
     1    25    21   260   250    26    25   .320   .20  0.50
    5.00   30.00
     2    37    34   260   250    38    37   .320   .20  0.50
    5.00   30.00
     3    41    37   260   250    42    41   .320   .20  0.50
    5.00   30.00
     4    53    52   260   250    54    53   .320   .20  0.50
    5.00   30.00
     5    28    32   260   250    27    28   .320   .20  0.50
    5.00   30.00
     6    32    35   260   250    31    32   .320   .20  0.50
    5.00   30.00
     7    44    45   260   250    43    44   .320   .20  0.50
   5.00   30.00
     8    58    62   260   250    57    58   .320   .20  0.50
   5.00   30.00
```

In the above sample file, there are 8 ramps. The simulator checks the ramp metering every 1.0 minute. The first ramp has a detector, which is between nodes 25 and 21. It is 260 feet upstream of node 21, and 250 feet downstream of node 25. The ramp is between nodes 26 and 25, has constant values of 0.320 and 0.20 and the ramp saturation flow rate is 0.5 vehicle/second. All the ramp metering is effective only between minutes 5.0 and 30.0.

VMS Data (vms.dat)

This file contains VMS configuration.

Table B.2. Description of the Input File vms.dat

Record Type	Field	Format	Field Width	Description
Number of signs	VMS_NUM	Integer	Free[1]	Number of Variable Message Signs.
Sign description	VMS_TYPE	Integer	Free	Type of VMS according to the following description. 1: speed advisory 2: route advisory 3: congestion warning.
	I1	Integer	Free	Upstream node.
	I2	Integer	Free	Downstream node (VMS are located at the downstream node).
	VMS(I,2)	Integer	Free	Type 1: speed threshold (+ or -). If positive (+), increase the link speed by a percentage as specified in VMS (I,3) (if the link speed is less than the threshold). If negative (-) decrease the link speed by a percentage (if the link speed is higher than the threshold). Type 2: the path number (among the K-paths --10) to which the VMS refers (note: 5 means path number 5 of the KAY shortest paths) Type 3: the percentage of class 5 users (VMS-responsive) who will follow the re-routing advice.
	VMS(I,3)	Integer	Free	Type 1: the percentage of reduction or increase in the speed of the link on which the vms is located Type 2: either 0 or a destination number. 0: the path specified in vms(i,2) applies for all destinations; when given a destination number, the path is applied for vehicles heading to this destination only. Type 3: Path preference for diversion. 1: current best path 0: a random path among K-paths.
	VMS_START	Float	Free	Start time for VMS (minutes).
	VMS_END	Float	Free	End time for VMS (minutes).

[1] Free format are separated by blank spaces

The following shows the format for this file.

```
16
1   23   28   40  10        0.0        20.0
1   30   25  -40  10        0.0        20.0
2   19   23    4   0        0.0        20.0
2   25   21    5 116        0.0        20.0
3   39   44   10   7        0.0        20.0
3   48   41  100   1        0.0        20.0
```
...

Of the 16 signs, there is a congestion warning VMS between node 48 and 41 (VMS number 6). This VMS will divert 100 percent of the class 5 vehicles (VMS responsive) that pass through the VMS link. Diversion will be made along the current best path starting from the downstream node of the VMS link. The VMS is active from minute 0.0 to minute 20.0.

Incident Data (incident.dat)

The purpose of this file is to specify the number of incidents to be simulated, their starting time, location, and severity. The method shown here is done in a pre-specified manner; however, the data can be readily modified in a real time execution. If a link is closed, all the vehicles will be rerouted after reaching the switching point (i.e. the upstream node of the link).

Table B.2. Description of the Input File incident.dat

Record Type	Field	Format	Field Width	Description
Total number of incidents	INCI_NUM	Integer	Free[1]	Total number of incidents
Incident definitions	IUNOD	Integer	Free	Upstream node of the incident link..
	IDNOD	Integer	Free	Downstream node of the incident link.
	INCI(I,1)	Float	Free	Start time of incident I (minutes).
	INCI(I,2)	Float	Free	End time of incident I (minutes).
	INCI(I,3)	Float	Free	Severity of incident I (as a fraction of capacity reduction).

[1] Free format are separated by blank spaces

The following shows the general format for this file.

```
2
48  41   5.0  20.0  0.5
39  44  10.0  25.0  0.5
```

There are two incidents, one is located between node 48 and 41, and the other between node 39 and 44. The first incident begins at minute 5.0 and ends at minute 20 while the second incident begins at minute 10 and ends at minute 25. Both incidents reduce their respective links' capacity by half.

It should be noted that even when the incident severity is set to 1.0, some vehicles can still pass through the link, though very few. In the current implementation, one cannot model complete link blockage through capacity reduction.

Pricing Data for HOV/HOT Lanes (pricing.dat)

The purpose of this file is to specify the toll values for the lower occupancy vehicles and the higher occupancy vehicles on the higher occupancy toll lanes and the general-purpose network.

Table B.4: Description of the Input File pricing.dat

Field	Format	Field Width	Description
PRICE_REGULAR_C	Float	Free	The toll value on every link in the general-purpose network.
PRICE_LOV_HOT_C	Float	Free	The toll value for the lower occupancy vehicles on the HOT lanes (links).
PRICE_HOV_HOT_C	Float	Free	The toll value for the higher occupancy vehicles on the HOT lanes (links).
TIME_VALUE	Float	Free	The dollar value of the time.

[1] Free format are separated by blank spaces

The following shows the general format for this file.

```
0.0     999.0     0.0     5.0
```

In the above example, there is no toll on the general-purpose network. Lower Occupancy Vehicles are charged $999.0 on each link of the HOV/HOT lane and no charges is applied to the Higher Occupancy Vehicles on those lanes. A value of time of $5.0 per hour is considered.