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RESEARCH AND TESTING FOR ITS DEPLOYMENT AND OPERATION

ABSTRACT

This paper identifies the elements of a publicly sponsored research and testing (R&T) program that best serves the needs of ITS deployment. Many of these needs derive from the decentralized, diverse, network-system nature of ITS. Relevant R&T should help integrate ITS technologies, data flows, services, organizations and users into effective, coordinated systems that can be tailored to fit diverse local needs. A key theme in an effective R&T program will be the effective generation and application of information, not only for users, but for planners, implementors and operators.

INTRODUCTION

The focus of this conference, "Realizing the Future," reflects an increasingly popular theme in the Intelligent Transportation Systems (ITS) community: *We understand the issues,* so this theme goes, *we know ITS works, we know* how t*o deploy it, so let's get to the point and start building and operating* . While we agree that deployment is the ultimate goal of all ITS research and testing, we don't believe that we know everything there is to know about how, why and when to deploy specific ITS functions. On the contrary, we believe that continued research and testing is still necessary to assure effective future ITS deployment.

This paper identifies critical needs for research and testing (R&T), especially as they are driven by the unique character of ITS deployment. This work is based to a large degree on our experience in the PATH research program (1), on case studies of ITS deployment we have performed (2), and on our experience in contributing to the Implementation Strategy of the National Systems Architecture Program (3). Specific R&T recommendations are contained in (1) and (3), some of which are repeated here in somewhat different form.

The subject of this paper is *applied* R&T in support of *ITS* deployment. While we cite some research needs that have broad, cross-cutting transportation applications, basic understanding of transportation science is not our primary focus, and we imply no negative judgment by any omissions in this area. We also largely ignore advanced vehicle control and automated highway systems, because of special requirements and longer lead times as compared to the ITS services that are the subject of this paper. Finally, our focus is largely public-sector research, because that is what we know most about, because of the significant role it can play in network system economies (see below), and because we feel that the private sector is the best judge of their own needs for research.

We identify strategic investments in R&T to facilitate early and sustainable deployments of ITS. The recommendations are *strategic* in the sense that we do not define specific projects, but rather outline major topics and key considerations. We do not connect our comments explicitly to the many ongoing R&T efforts sponsored by USDOT, nor do we attempt to develop a R&T program plan in detail. Instead we paint in rather broad strokes the principal dimensions of an effective public ITS R&T program.

We begin by identifying the unique features of ITS deployment that drive R&T requirements. In general, these features lead us logically to the necessary characteristics of an R&T program, which we describe thematically, as well as by specific project categories. In some cases, however, we simply pose problems and dilemmas for a research program and do not claim to resolve them completely, leaving the reader, we hope, with a realistic insight into the real challenges that still face the ITS world.

ITS DEPLOYMENT HALLMARKS

1. *Deployments have strong* local *character.*

Increasingly, public transportation planning, financing, deployment and operation are state, regional and local affairs, with authority and responsibility steadily moving to more local levels. In most cases, "local" further breaks down into various independent, specialized local agencies, such as for transit, emergency response, and police. The local character of ITS deployments is further amplified by the significant diversity of local needs, resources, values, networks, land-use patterns, and existing levels and types of infrastructure deployment (2).

2. *ITS are* network systems.

ITS is a "network system" because users and operators must connect together and interact for varied purposes through shared information by means of multi-purpose interfaces in different locations. Because of this network-system character, there are "external benefits" to users of the network resulting from coordination and standards. (Each individual user of the system benefits from the fact that all users submit to some degree of coordination or standardization.) The National System Architecture was predicated on facilitating use of ITS services through an open architecture and appropriate interface standards.

Note that 1. and 2. together produce a certain tension: In some ways, components of ITS must work independently, in some ways they will work best through certain kinds of coordination. The lesson here is that certain strategies that facilitate decentralized coordination and control are likely to be effective compromises between the reality of local control and the (sometimes) substantial benefits of coordination. (We return later to the important question of conditions under which coordination benefits are significant and are likely to justify the costs of coordination--and what these benefits and costs are.)

3. *There are diverse, multiple users and stakeholders.*

System users range widely from single-occupancy vehicle operators (which themselves come in multiple flavors) to transit users to commercial vehicle operators. Stakeholders include many groups with strong interests in transportation impacts, from the environment to the economy. This point is a truism to anyone who works in the business of road transportation. It is worth citing, however, because it effects research and testing in crucial ways, most importantly because it vastly complicates the assessment of the balance and distribution of benefits and costs among users and non-users.

4. *There are likely to be diverse, multiple producers and operators, public and private, with the private sector dominating some emerging sectors.*

Again, this is a point long understood in the ITS community, but it continues to complicate deployment questions when combined with continued uncertainties about the benefits and costs of various ITS products and services. It also implies that we are at the beginning of what may be a long period of evolution of new institutional arrangements for effecting good public-private division of responsibilities.

The private sector will clearly lead in the development of personal navigation and transportation information devices, with no government control, but possible public use through voluntary participation by drivers. It is also likely to have a critical leading role in efficiently managing and delivering other emerging ITS services, in areas where the overall responsibility (and funding) will continue to be public, e.g. in providing traveler information.

5. *Some important benefits tend to occur to a greater degree with ITS than other surface transportation system improvements currently practical, and these benefits elude easy evaluation.*

ITS may enhance both "Mobility" (4) and travel time variability, yet these are difficult effects to assess.

6. *ITS will ride a communication and computer technology wave on which ITS itself has little effect.*

This technology is rapidly improving in performance and cost, although ITS itself doesn't set this agenda. Communications and computer technology will support many functions with increasing cost effectiveness: the coordination of transportation services among governmental agencies (increasingly involving rich and varied interconnections of Traffic Management Centers), vastly improved access to all types of information (based in part on a greatly increased capacity for land-line communication), automatic system performance reporting, expanded capabilities for real-time transit scheduling and routing, expanded use of cellular phones (enabling more individual travelers to report accidents and access information services), and widespread use of surveillance systems based on new technologies, providing vastly improved capabilities for detecting and assessing incidents.

All these factors lead to a final pair of characteristics that successfully deployed ITS is likely to have (and ITS technologies make possible):

7. *ITS deployments will be flexible in their ability to adapt and/or refresh themselves as technology, markets, networks and standards evolve. Control will tend to be decentralized, permitting maximum beneficial local distinctions in service and organization to persist, while taking advantage of the benefits of coordination through decentralized means. Massive, special-purpose infrastructure is unlikely to persist except as museums of past folly.*

8. *Maximum use will be made of increasing amounts of information to exploit system flexibility, to adapt systems over all time scales, from real-time to long-term. Thus, improved information can be the basis for both operational and evolutionary system improvements, provided systems are structured to be able to make such changes and to exploit information for these purposes.*

R&T MOTIVATIONS, GOALS AND STAGES

Publicly sponsored ITS R&T is important because of the *network system* nature of ITS. Because the benefits of public infrastructure and interface standards accrue not only to a single private firm (who in principal could finance the supporting R&T, but will not because it cannot retain the benefits for itself), but to entire populations of firms and consumers, it is necessary that the enabling relevant R&T for developing the infrastructure and standards be sponsored by the government. The critical role of standards has been further amplified by recent developments: local and regional authorities have increased authority and responsibility for infrastructure implementations, so that standards become a vital means of achieving the goals of interoperability, with associated payoffs in performance and cost. Standards can also make possible cooperative vehicle-infrastructure strategies (such as cooperative road markings) that can decrease costs and increase performance. Standards become a critical means for enabling ITS to connect with rapidly evolving communication technologies, themselves developing in an increasingly decentralized and de-regulated environment.

The normal USDOT stages of project funding from research and testing through deployment are listed in Table 1.

The second column of the table gives generic characteristics of the various R&T stages. The third column gives examples of projects from the ITS world for each stage, together with identification of where current USDOT ITS projects fit, by category (italicized terms in the last column refer to specific categories of USDOT programs).

The characteristics of the various R&T stages in ITS also have implications for the management of R&T. This topic is taken up in the next section.

R&T STRATEGIES

To be effective, ITS R&T must be closely coordinated with deployment , as well as technology development in the private sector. R&T should have the goal of ensuring that technologies and systems are selected, planned, deployed and integrated in a manner that maximizes their effectiveness in solving the nation's transportation problems. Federal R&T must have the specific goal of facilitating local deployments that in the future will be both diverse and independent of direct federal control. These factors make the acquisition of appropriate information from R&T at once more critical and more challenging.

A primary goal of the research program outlined in this section is to facilitate deployments in this diverse environment by focusing on issues related to the architecture and associated standards. As cited above a critical federal role in R&T exists precisely *because* of the network and system character of ITS; thus much of valuable federal R&T will be associated with the systems aspects of ITS: how pieces fit together and communicate with each other effectively.

Another crucial way in which Federally sponsored R&T can aid in deployment is through the evaluation and prediction of the performance of alternative system concepts. By providing credible and relevant assessments of technical performance, costs and benefits, R&T can promote effective deployments.

Federally supported R&T should not compete with the private sector, e.g. in the area of technology product development. The marketplace is an effective mechanism for supporting technology innovations in relevant applications, with private sector R&T investments recouped through the sale of deployable technologies and services to individuals, businesses and government. In specific cases, the federal government may conduct or finance R&T in technology development, but only when there is a unique need and the technology is unlikely to be developed without also performing fundamental R&T, e.g. in cases where there is a very long lead time and high uncertainties. If the R&T benefits also accrue to all members of an industry, then there is further motivation for the government to assist. Clearly , R&T connected with the development of standards satisfies this criterion.

R&T MANAGEMENT POLICIES

Important functions of R&T management are to provide: i) clear themes and objectives, ii) relevance to real *local* deployers, iii) continuity, iv) flexibility, and v) prompt and decisive response to new information and developments in technology, the market place and institutions. In order to respond effectively to new information, R&T management must have sufficient good alternative options, as appropriate to the current level of uncertainty about the viability of a technology. It won't have these options unless it's prepared for bad as well as good news (and therefore research managers should work to insure the independence of the researchers). Finally, and of overriding (but often neglected) importance, R&T management must **identify R&T topics by assessing the uncertainties that the research is intended to address, and the payoffs that would accrue (and to whom) with the removal of these uncertainties with successful research, and finally by performing a cost-benefit analysis that weighs all these factors, including the cost of the R&T.** Put simply, if the R&T is not likely to matter when it comes to eventual deployments, *don't do it.*

Government R&T also serves the nation's needs for trained personnel by expanding educational opportunities in transportation, and by training future transportation professionals in relevant disciplines. If the R&T topics are relevant to the purpose of deployment, then professionals will automatically be trained in relevant disciplines and perspectives. *It is particularly important for ITS to train professionals that have a multi-disciplinary, systems perspective.* Many of the R&T topics outlined below have this character.

Once funded, the sponsor is responsible for assuring that findings are communicated to the relevant community of interest. This latter function is a particularly important and appropriate function of government, and is especially relevant to ITS applications because of the multiple deployers, operators, private providers and users, and *because of the centrality of information and communication to ITS.* Thus, ITS should be, by its nature, particularly suitable for communication of results and lessons.

Sponsoring agencies may also pursue cooperative R&T projects with private industry. Such partnerships occur when private sector participation enhances the agency's ability to respond to high priority R&T initiatives. In particular, private sector participation can provide additional funding, amplify an agency's ability to manage and implement large-scale R&T projects, as well as provide complementary technical skills, especially in product areas. Perhaps most importantly, joint projects provide an opportunity for public and private agencies to develop effective ways of working together through learning by doing.

R&T PRIORITIES

Within the above guidelines, we identify the following as particularly important R&T topics:

System Architecture and Integration for State and Local Deployments Investigate how the national system architecture can be best applied to develop "regional architectures" that satisfy state and local needs and constraints, while achieving the major goals of the national architecture. Determine how such regional architectures can help improve *coordination and integration*: among governmental agencies, among different transportation modes, among services (including non-transportation ones), between government and the private sector, and between government and individual travelers. Identify critical connections among institutions, technology and operations, and the benefits as well as the costs of coordination. Develop guidance on when coordination is cost-effective and when it is not. Identify the role of standards in the facilitation of inter-agency, multi-function coordination and in the acceleration of deployments. This R&T can help guide the standards development process by identifying how specific standards facilitate coordination and deployment.

Data Collection and Storage for R&T, Evaluation, Planning, and Operation ITS makes possible the acquisition of huge quantities of valuable, real transportation data. We need to understand better how to collect, manage, retrieve and apply this data on a project, regional and national level, in a wide variety of real-time and archival applications. Relevant data include traffic flow, travel demand, trip generation, market demand for travel and traffic information, and technology and system performance. Consideration should be given to providing incentives for appropriate data collection in projects that use federal funds. Establish an automated, nation-wide transportation reporting system. It will be critical to promote standards for data types, quality and formats, to insure maximum communication ease and relevance.

State-of-the-art data base approaches should be used to promote efficiency and ease of data exchange and use. For example, object-oriented databases are capable of integrating key model elements: traffic simulation packages, data sets, and computational tools. In turn, this kind of approach can efficiently guide and facilitate new software development.

Because of the intense needs for data in ITS systems analysis and design, and the requirements for efficiently sharing large quantities of information among many users and applications, we expect such smart databases to have high value in the future, both for researchers as well as implementors. An important question is how best to apply these technologies for the most cost-effective storage and retrieval of data for specific transportation management, planning and research purposes.

At the operational level, we need to investigate how information (and appropriately designed management processes) can be used to support and motivate performance improvements in the delivery of ITS services.

Data Acquisition Technologies and Systems Within the framework of the NSA, investigate the data required for control, performance monitoring and information dissemination purposes. Investigate alternative means for acquiring, processing and communicating data from remote sites. Data acquisition methods will include both direct surveillance (via loops, video, and other imaging, detection, identification, and tracking techniques, and vehicle as probes). Analysis must not only include the technical performance of sensor technologies, but the system aspects of communication requirements, standards compatibility and the impact of sensor systems on overall system performance. Models should be developed that support cost/benefit trade-offs between system performance and data acquisition costs. Testbeds and Field Operational Tests will play an important role in confirming the most cost-effective mixes of technologies for specific purposes.

Traffic and Travel Analysis and Simulation for ITS Although much effort has been expended on developing traffic analysis methods, models and simulations over the past 30 years, currently available approaches are unable to capture the impacts of many promising ITS functions. This is an area where national attention is vital to avoid duplication of effort, and to organize critical masses of resources to attack a difficult and challenging problem.

With regard to system architecture, it is important to develop simulation tools that capture the effects of specific information flows and uses, as well as corresponding decisions (management system as well individual traveler). Of particular architectural interest are: 1. simulations that capture adequately the effects of coordination across services, regions and modes, as well as traveler behavior in the context of ITS services, and 2. identification of appropriate interfaces to and from on-line simulations (see "Short-Term Forecasting" below), to enable simulations to be linked efficiently into operations.

We need standard approaches to evaluate and compare models with respect to numerous criteria: how they model traffic dynamics, and how they represent networks, intersection signal control, multiple driver classes, route selection approaches, vehicle types, incidents, special devices, and demand management. Models need to be classified for suitability for specific purposes, e.g. planning vs. real-time operational control. We also need to identify outputs and requirements for input data, hardware, memory and computational run-time. We must be able to evaluate models for their validity, to determine whether the outputs are consistent with “known” or anticipated results, and if the model outputs are unduly sensitive to any input parameters. Such an investigation, if performed with standard criteria and base data sets, will be helpful to the whole community in improving and establishing solid R&T and evaluation tools.

Useful simulations will have to be able to assess a range of meaningful system and user performance measures, e.g. travel time distribution, mean and variance. One particular measure that has received increasing attention with the advent of ITS, but as yet remains most difficult to evaluate, is "mobility". Mobility represents the benefits to individual travelers of increased knowledge of travel options and conditions (through greater trip and associated activity utility); sufficiently rich models to be able to estimate mobility benefits would be useful in settling debates about the importance of this benefit.

Short-Term Forecasting This need is an important near-term aspect of general traffic simulation requirements. Statistical methods are needed for real-time estimation of system performance as well as short-term forecasting of traffic. These methods would be used within TMCs to: (1) optimize the selection of control strategies, and (2) develop dynamic travel time estimates on an origin/destination and link basis. The travel time estimates could be further used within route guidance systems to identify shortest travel time paths in real time. Travel time estimates would also be incorporated within the TMCs' performance monitoring systems, to track average travel times on a day-to-day basis. An important topic is the integration of simulations into TMC architectures.

Transportation Management Center (TMC) Coordination A significant amplification of benefits and greater economies may occur from combining and coordinating functions across related services and across different modes and adjacent regions. Transportation Management Centers (TMCs) are becoming the central focal points for monitoring and managing transportation systems, and they bring the possibility of such improved coordination and resulting benefits.

A number of regions have made great strides in developing TMCs, and in coordinating certain functions such as traffic management and law enforcement. Despite these accomplishments, however, TMCs have yet to achieve their full potential for becoming the nerve centers of a large array of traffic management functions. Effort is needed to determine the best way to integrate a greater scope of advanced ITS functions into TMC operations, to extend them to the coordination of more functions, modes and agencies, and to support them with appropriate mixtures of computer automation and operator involvement. Key architectural issues include how to select a regional architecture that best fits local needs, local institutional conditions and existing and projected communications infrastructure; how to assign responsibilities and authority in specific multi-agency, multi-service contexts; and how best to integrate technology and management structure, paying particular attention to how to maximize incentives for improving efficiencies and service. Another key question involves how best to incorporate the private sector, either as a direct and independent service provider, as a partner, or as a contractor to a public agency.

Institutional and Organizational Phenomena Of the many important ITS institutional issues the ones of most direct concern to architecture are the following: 1) What are the institutional barriers to inter-regional, intermodal and inter-functional coordination, when are they worth overcoming, and what are the best approaches for overcoming them? 2) How do these barriers interact with various technological, operational and organizational options for their amelioration? 3) How do we best integrate the private sector into the delivery of services?

Field Operational Tests are an important mechanism for trying new organizational arrangements to develop and support ITS services. We believe that important models are emerging from these tests through hard-won experience, and that effective roles for the private sector will thereby be developed. The mechanisms for this knowledge acquisition are not always the ones anticipated by test developers; instead some of the mechanisms are distinctly informal: 1) *learning by doing*, and 2) *networking*, i.e. the development of effective ITS professional and business relationships. Some of the organizations that enter the next round of ITS development will have been substantially enriched by these means.

Benefits and Costs Evaluation Many of the R&T topics cited above either directly or indirectly contribute to the evaluation of benefits and costs. However, the problems of usefully evaluating benefits, in particular, will remain daunting unless more effort is put into framing benefits evaluations in ways that diverse regional and local decision makers will find compelling and useful. Present evaluations are often unused, for a variety of reasons: unsound methodology, unjustified or indeterminate assumptions and parameter specification, unvalidated (or clearly inaccurate) simulations, lack of valid estimates of uncertainty in benefit estimations, lack of a reference base case, and differences between the test or simulation conditions and the conditions of interest to a potential deployer. Some benefit assessments take a "maxi-max" approach of estimating the maximum benefits under the most suitable circumstances for ideal users, and then adding these up without regard to the representativeness of these results for real travelers engaged in a real ensemble of trips. Much of the R&T called out here will address these problems, but more is needed, along the lines of the establishment of "good benefits/costs-evaluation standards and practices" that address all the above problems, and encourage researchers and testers to pay attention systematically to these issues. In addition, it would be extremely valuable to develop methodologies for "evaluating evaluations," to frame benefit and costs assessments to assist implementors in efficiently accessing and using the data most relevant to their problem.

Integrated Planning Tools System integrators, public and private, need tools for combining the above-cited capabilities (data collection, analysis and impact assessment) into an integrated tool set to support cost-effective deployment decisions. A successful tool of this type is likely to be evolutionary in nature, with the ability to incorporate new data and models within a methodologically sound overall framework.

TESTING AND SYSTEMS ARCHITECTURE

In hindsight, early FOTs have turned out to be less predictable than originally believed. A partial explanation is found in the common character of ITS tests. Most FOTs, even the simpler ones, are new *system* deployments, involving: 1. interconnections of new (or newly adapted) technologies, by new operators, in new contexts and applications, with new users, and 2. requirements for cooperation in planning, deployment and operation of new agents in new partnerships. Even when all the pieces have been tested and proven in isolation, there are typically enough new connections and coordinations required that new, *system* risks arise. In the evolution from research to deployment of a set of ITS technologies, FOTs often confront for the first time the architectural issues of interfaces and coordination (at both technical and institutional levels), and this accounts for much of their challenge. As the architecture and associated standards are adopted, many of the problems and risks encountered by these FOTs will be ameliorated, but not entirely eliminated.

Future testing should build upon the results of DOT's ongoing FOT program. Tests should be planned through a formal decision process established for managing R&T in a coordinated fashion over time. It will be important to clearly identify costs, benefits and uncertainties, and who will use the information anticipated from the tests, for what purposes and potential benefits. Finally, the information should be put into usable forms and widely disseminated (see especially the Data Collection R&T topic above).

A testing program relevant to the National Systems Architecture should be developed consistent with the following guiding principles:

1. FOT evaluations (including those of ongoing tests) should systematically report on relevant architectural issues, e.g. the effectiveness of standards as employed in the test, or recommendations of standards arising from the test experience. A potentially useful related project would be to cull past and on-going FOT efforts for experience and advice on standards issues, and to structure and classify this information in a way that would be most useful to standard-setting efforts, as well as to other operators and implementors.

2. Future FOTs should include tests of the integration of telecommunication technologies with specific applications and users. Evaluation goals should be the cost-effectiveness of the integrated system, its "marketability" and usability. Tests should be defined carefully by selecting the most promising combinations of telecommunications technology and applications, and fielding them in the most promising and representative institutional and operational settings. The main object of these operational tests should *not* be telecommunications technologies themselves, as they are largely well understood and technically adequate for a range of applications--see Sec. 7, Communication Technology Assessment, of the "National ITS Communication" document (5). Rather, the key questions are *how communications and applications fit together into the operations of transportation agencies, and how this combination can deliver desired, cost-effective services to users who are willing to pay for them.*

The design of such tests involves considerations of application priority, technology promise and fit, and effective partnership structure. Because of this complexity, it is not possible or appropriate to design or recommend specific tests here. Instead we have recommended important underlying principles and goals that such tests should satisfy if they are to support ITS implementation consistent with the National Systems Architecture.

CONCLUSIONS

Publicly sponsored R&T must address the issues that are most critical for ITS deployment but will not be addressed by the private sector. A basic goal is the integration of ITS technologies, data flows, services, organizations (public and private) and users into cost-effective systems that can be readily adapted to fit specific local needs. R&T should explicitly consider the actual decisions and uncertainties faced by real state, regional and local deployers; research priorities should be informed by the potential benefits of improving the quality of these decisions. An important objective is the development of tools and data bases for the efficient assessment of system impacts, costs and benefits expressed in a framework that is useful for actual deployers. A fundamental common theme to ITS R&T projects is the effective generation and application of information, not only for users, but for planners, implementors and operators.

ENDNOTES

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3. *Implementation Strategy Document*, National ITS Architecture Team, June, 1996.
4. D. Brand, "Intelligent Vehicle Highway System Benefits Assessment Framework," Transportation Research Record 1408, 1994.
5. *National ITS Communication Document*, National ITS Architecture Team, June, 1996.

Table 1 R&T Stages

R&T Stage	**Characteristics**	**ITS Examples**
research and development	determination of feasibility of specific technologies and tools; highly to moderately unpredictable	feasibility of new algorithms for detection and control; new sensor development; improved simulation tools
testing	prototype testing; full system tests; moderate predictability	*Testbeds* for specific technologies; *Field Operational Tests*
demonstration	first full-scale operating example; high predictability	*Showcase Projects*
deployment support	post-testing support for actual deployments; direct application of relevant R&T results	*Early Deployment Planning; Deployment Support*