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# **Why ITS Projects Should be Small, Local and Private**

**Stein Weissenberger**

**California PATH Research Report  
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# **Why ITS Projects Should Be Small, Local, and Private:**

Lessons from Studies of  
Technological Change  
for the Deployment  
of  
Intelligent Transportation Systems

Stein Weissenberger

University of California  
PATH Program

February 16, 1998

Until Jove let it be, no colonist  
Mastered the wild earth; no land was marked,  
None parceled out or shared; but everyone  
Looked for his living in the common wold.

And Jove gave poison to the blacksnakes, and  
Made the wolves ravage, made the ocean roll,  
Knocked honey from the leaves, took fire away--  
So man might beat out various inventions  
By reasoning and art.

First he chipped fire  
Out of the veins of flint where it was hidden;  
Then rivers felt his skiffs of the light alder;  
Then sailors counted up the stars and named them;  
Pleiades, Hyades, and the Pole Star;  
Then were discovered ways to take wild things  
In snares, or hunt them with the circling pack;  
And how to whip a stream with casting nets,  
Or draw the deep-sea fisherman's cordage up;  
And then the use of steel and the shrieking saw;  
Then various crafts. All things were overcome  
By labor and the force of bitter need.

Virgil, *Georgics: I, Work and the Earth*  
trans. Robert Fitzgerald

You can't always get what you want,  
You can't always get what you want,  
You can't always get what you want,  
But if you try sometimes  
You just might find  
You get what you need.

Mick Jagger

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## **Executive Summary**

As with any new technology, implementation of Intelligent Transportation Systems (ITS) requires the acquisition of new technical knowledge and the development of new supporting institutions. Multi-disciplinary studies of technology development show that these institutions and knowledge can only be achieved through intimate and idiosyncratic processes of *learning by doing and using*. The resulting “embodied knowledge” cannot be readily acquired or communicated through distant, anonymous agents. Hence, in order to produce and capture useful knowledge, early ITS projects should be local, small, and focused on realistic goals. At the same time, because of the complexity of ITS systems, their planning, deployment and operations should be executed through intimately cooperating networks of individuals and organizations that support knowledge acquisition and diffusion. Private industry should be used wherever possible, especially to perform tasks for which they are best qualified; they should be looked upon as a sources of skills rather than as a source of funding. Early on, it is important to *do* something, even if limited in scope; it will be much less useful (both to satisfy local needs and to further the development of ITS) to attempt grandiose projects, even if funding is successfully obtained from distant agencies. At the early stage, it is more important to build (and depend on) networks of experienced experts and operators than it is to try to build large interconnected networks of ITS implementations.

Following general “laws” of technology development, as services and products mature they become more useful, standardized, less expensive, and easier to operate, maintain, and interconnect. Local projects and services can then be replicated, adapted, and joined together into larger systems.

The following are highlights of specific findings:

ITS projects need to match local requirements and markets. Successful projects are therefore likely to have distinctly local flavors, as exemplified by cases such as the cities of Los Angeles, Anaheim, and San Jose. The value of these projects also tends to be more transparent to users and operators, obviating the need for difficult and often problematical benefit-cost analysis for their justification. A large set of similar projects performed in many different localities will also be more capable of extrapolation to new, specific settings because of the great variety of local conditions across the country.

Costs of coordination and interoperability (among technologies, services, and agencies) need to be realistically assessed and weighed against corresponding benefits. Localized services should be mastered before adding linkages. Whenever possible, coordination should be facilitated through evolutionary paths, rather than by attempting to implement massive, single-shot, top-down designs.

Public policy should emphasize the early development of supporting institutional networks and their *coevolution* with technology implementation. Prompt development of these *learning networks* is more important than the

development of ambitious ITS plans or the premature deployment of complex operational ITS networks. The key is to help agents work autonomously to build deployments with minimum dependence on central planning and control.

ITS is a “complex” or “assembled” technology, involving the integration of many sub-systems, specific technologies, and institutions, and with critical knowledge distributed over many individuals and organizations. *Learning networks* and *learning by doing and using* are particularly critical ingredients for the deployment of such systems, and so it is especially important to facilitate them in the early development of project portfolios.

Many aspects of early ITS deployment involve incremental innovation, while some longer-term ITS technologies require more radical innovation. Early small projects will contribute to the development of learning networks that can support a broad range of future innovation processes, both incremental and radical, as they are called for.

For ITS functions that require incremental, evolutionary innovation, a high degree of integration is necessary among research, developmental, and operational activities. For those functions that require radical innovation, such as highway automation, a greater degree of early independence of the R&D functions from operational ones is important.

Privatization of ITS service provision should be facilitated. Public agencies should be permitted and encouraged to develop and test alternative mechanisms for involving private companies. Public-private learning networks will also be assisted by this process, as they will by any actions that focuses on *doing and using*.

In public/private partnerships, each party should take on the tasks that best fit its existing core capabilities and missions. Public agencies should not attempt to take on technical or managerial tasks for which they are unprepared (manage complex systems developments, provide high-quality, tailored customer services), nor should they expect private companies to behave in ways for which they are unsuited (take high financial risks, understand the public planning, programming, and regulatory processes). By exploiting complementary and core strengths, much more effective partnerships can be formed.

ITS operating performance should be much more carefully and universally measured, based on objective criteria and procedures. This data will be valuable for operations management as well as for regional planning. The availability of such data will also make meaningful strategic benchmarking possible, to facilitate practical long-term planning. Regional, multi-partner testbeds (such as the Southern California Testbed) are ideal mechanisms for developing such measurements and measurement systems.

The California State Route 91 Variable-Toll Express Lane Facility is an exemplar for the principal assertions of this study. A privately financed and operated toll road exclusively employing electronic toll collection, this project is distinctly small (approximately ten miles of four-lanes) and predominately private. Of special note is the nature of the private-public partnership involved, where each party (the private partners and Caltrans) has taken on tasks that perfectly match their core capabilities. Best of all, the facility has attracted large use and the partners are thereby gaining valuable information about their market and technology, laying groundwork for subsequent expansions and duplication.



## 1. Introduction

### 1.1 Goals, Background, and Framework

My goal in this work is to draw some principles from studies of technological innovation and to apply them to Intelligent Transportation Systems (ITS). Without aiming for completeness, I try to complement what is already known about ITS deployment, to fill in certain gaps in the existing ITS literature, and to stimulate reflection and further research.

ITS was first successfully initiated in the US as a major national program under the name “Intelligent Vehicle Highway Systems” in the early 90’s. This followed largely abortive national developmental attempts in the late 60’s and early 70’s, some specific successful local implementations such as the Los Angeles ATIS system in 1984, and then further national conceptual and promotional development in the mid- to late 80’s, and finally a seminal articulation by Mobility 2000 (Saxton, 1993, and Shladover et al, 1993). By now there has been some six years of intensive nation-wide research and development, testing, and early implementation. During this period, over \$1B of federal funding has been spent, as appropriated in the ISTEA (Intermodal Surface Transportation Efficiency Act) legislation of 1992, with notable programs including numerous national field operational tests across the country, the development of a national ITS architecture, and the completion of a series of demonstrations of Automated Highway technologies; state and local governments have planned, tested and implemented ITS (see e.g. California Department of Transportation, 1997, Texas Department of Transportation, 1995, and Loudon et al, 1997); and a major national organization, ITS America, has promoted ITS implementation and published national strategic plans, beginning with (IVHS America, 1992).

After the expenditure of this time, effort and money much has been learned and accomplished; nevertheless, the resulting working deployments are fewer than many had originally hoped--early ITS proponents foresaw wider implementation and impacts of ITS by the millennium (see, e.g., the projections in (IVHS America, 1992)). Many ambitious ITS projects have been reduced in scope, while others have fallen short of their goals. While I do not pretend to entirely explain the current state of ITS deployment, I have tried to identify principles that illuminate the current condition and provide guidance for improvement.

Following are some of the specific objectives and limitations of this study:

1. A major objective is to survey and assemble relevant research on technology innovation, and to begin to connect this large literature with the ITS world. In some cases, these connections will be confident, in others, only suggestive, and further research will be suggested.

2. ITS is a broad field, and I do not cite each of its technologies, systems and services in detail. Instead, I use examples of particular services as I develop and illustrate themes. In particular, I focus on near-term ITS functions (within the next 15 years), and have less to say on the longer-term ones such as highway automation. I also draw exclusively on US examples and experience.

3. My advocacy for “private” ITS development and deployment echoes the standard wisdom in the ITS literature of the past decade for the need for “public-private partnerships”, with the private sector playing the largest role in ITS deployment. However, my goal is to add to the rationale for the private role and the value of privatization. For example, I believe there has been a misguided emphasis on the private sector as a funding source, and not enough on the core competencies that the private sector brings to ITS implementation--the skills and incentives to work through markets to develop products and services that customers want.

4. While I identify roles for the private sector, most of my advice is aimed at *public* policy to support more private involvement.

5. The reader looking here for recipes for ITS implementation will be disappointed. Instead, I hope that the discussion will be useful for reviewing and synthesizing real implementation plans and policies, by drawing attention to critical principles. (A significant body of work exists on the topic of developing specific deployment plans and strategies; for some ITS examples see, e.g., Tsao, 1998, Lathrop et al, 1998, Al-Ayat et al, 1994.)

6. The public transportation planning and programming process is exceedingly complex. (See, e.g. (Horan et al, 1995), for a discussion of associated issues and implications for ITS deployment in California.) Although clearly all ITS projects will have to work their way through this system in one way or another, I ignore these processes here and carry out this study at a level largely independent of their details. I do account for it, however, in noting that this arena is one of the natural responsibilities for public agencies like Caltrans in any public-private partnership. I also urge that ways be found to link the planning process much more closely to those who research, test, design, and operate ITS systems. One of the ways to improve this linkage between planning and operations is to improve the measurement of ITS performance. Another way is to give more active voices and roles to testers, evaluators, and operators in the planning process.

7. My advice supports a “self-sustained” ITS deployment system: I’ve tried to identify factors that permit local and private agents to deploy successful systems, in contrast to “top-down” approaches that require extensive central planning, guidance, and implementation.

8. It is a commonplace that ITS deals in “network system” technologies, with significant benefits arising from its network system nature. Many ITS services clearly exhibit (at some scale) increasing returns to scale, both through increasing market size and through increasingly valued services to consumers that arise from interconnections. Many of the implications of this character have been clearly and frequently articulated, see e.g. Weissenberger et al, 1996. The national system architecture and the current standard development processes reflect this understanding, and are unambiguously desirable developments at the national level to facilitate the long-term deployment of ITS. Similarly, I endorse the commonplace advice on the need for better research, tools and education in systems analysis and integration. (Even the smallest and most local ITS projects will have a significant system character; furthermore, no matter how small contemporary projects presently are, they will tend to become larger and more complex in the future.) In this study, I take all these facts as given, and explore *other* implications of the “system-ness” of ITS, especially ones that suggest advice that is counter to the now rather standard ITS commandment of “connect everything to everything else.”

My goal is to emphasize some advantages of smallness and locality, not to deny all the virtues of interconnectedness.

9. The “small, local, and private” in our title is seriously intended. However, it’s obvious that in any real case, numerous particular conditions can qualify or even negate this simplified advice. I have not attempted to identify all those situations in which some or all of “large, national, and public” may be the better path. It’s also true that these words do not always have obvious and precise meanings. For example, I will use the SR-91 private toll road as an exemplar of “small, local and private.” While this project does unambiguously fit the latter two qualifiers, it isn’t clear on the face of it that it fits the former--I consider it to do so by comparison to many much larger alternatives. Why something is “local” in this study will be clear from the context.

## 1.2 Overview of Technological Change

Successful technological innovation is to a large degree a process of *practical knowledge acquisition*. This process does not often follow the idealized process of research, development, testing and implementation, nor is useful technical knowledge transferred solely (or even most importantly) through simple, direct, and obvious processes.

Because *all* of technology can never be translated into words, pictures, or mathematical equations, the practitioner with a hands-on knowledge, be it of eighteenth-century textile machinery or twentieth-century computers, will always have a role to play in the dissemination of technical innovations. Although much of modern technology can be gleaned from books, articles, monographs, and patents, the artifacts must be studied at first hand, oral

information gathered from persons conversant with the new technology, and the innovations adapted to the recipient economy and culture.

(Basalla, 1988)

Basalla describes how the English obtained the Italian technology of water-powered silk-throwing (silk-thread production) in the early 18th century. In spite of their possession of an engraving of such a machine, they were unable to replicate the process until they had placed an Englishman, John Lombe, in Italy for several years, during which time he was able to master all the important details of the machine's construction and operation. Then when Lombe returned, it was his half-brother who constructed a mill based on his acquired knowledge--an early example of an intimate "learning network" relationship in the technology transfer process.

"Learning networks" are the formal and informal networks that support the development of any technological innovation, especially ones with the complex systems character of ITS. These networks range from the movement of people between organizations, the informal interchange of information through personal contacts, information exchange through professional associations, informal agreements among firms, and formal cooperative arrangements. Such networks have become increasingly important for "complex" technologies (Kash and Rycroft, 1997), and they are discussed in some detail in Section 3.

### The Knowledge Acquisition Process

"Learning by doing," or "learning by using," are the dominant methods by which technologies are "learned" and improved (Rosenberg, 1982). "Doing" involves experience with the production process, while "using" involves the customer's experience with the product; both types of experience are crucial for innovation. The majority of technological improvements are incremental ones, and depend on an intimate knowledge of the technology and how it is used, as well as complementary technologies, systems, and institutions in which the technology is imbedded. Rosenberg distinguishes between *embodied* and *disembodied* knowledge: embodied knowledge is associated with the details of the technology, and is required in order to make improvements in those details, while disembodied knowledge can be summarized in terms of operating characteristics and performance. Both kinds of knowledge are acquired through learning by doing and using, but only disembodied knowledge is readily communicated through formal, explicit means (e.g. books, journals, websites).

Of particular relevance to ITS and the surface transportation setting, Rosenberg (1982) observes that

For a range of products involving complex, interdependent components or materials that will be subject to varied or prolonged stress in extreme environments, the outcome of the interaction of these parts cannot be

precisely predicted. In this sense, we are dealing with performance characteristics that scientific knowledge or techniques cannot predict very accurately. (p.122)

In later sections these principles will be illustrated by examples of successful and unsuccessful approaches to the implementation of complex transportation systems.

A broad understanding of technological evolution and change has emerged in the last two decades. For a recent survey of the large and growing economics literature on technological change, see Freeman (1994). In Section 2, I adopt the particular framework and terminology of Utterback (1994) to describe the fundamental factors involved in technology change--the basic story is consistent with Rosenberg and others, but Utterback provides a particularly concise and clear framework for our analysis of ITS.

In Section 2 and 3 I rely primarily on analyses from the economic literature on technology innovation. There is also a large literature that focuses on the engineering design process; the work of Petrosky (1992a,b,1994,1996) identifies many of the same principles found in the economics literature, but emphasizes the details of the design process, rather than the economics of knowledge acquisition. He gives many interesting examples of the design of everything from paper clips to beverage cans to bridges, and is particularly useful in developing a feeling for some of the factors that are cited in the economics literature, but rarely illustrated there so vividly: the complex challenges of producing improved designs of even apparently simple objects (like paper clips or beverage cans), the critical importance of small design details (the design of a connector for a suspended walkway that subsequently collapsed); the basic, evolutionary process of *incremental* design (how the food fork evolved); the critical role of error in the production of successful designs. Petroski's "engineering judgment," gained from an intimate knowledge of failures and near-failures (Petroski, 1994, p. 122), is equivalent to the "embedded knowledge" of the economists. These ideas reappear in Section 4.

In the same spirit as Petroski, another engineer, Walter Vincenti (1990), has made a detailed study of the development of aeronautical technology (the majority of Petroski's case studies are civil and mechanical). This work follows complex aeronautical technologies through four detailed case studies from inception through evolutionary development on to maturity. Among the important points made by Vincenti are:

1. Design is a *variation-selection process* of knowledge generation, typically proceeding in iterative steps.
2. The process involves a *nested hierarchy*, with subsidiary variation-selection processes going on in parallel with the main design task.

3. The entire process is *dynamic*, with the details of the process evolving over time, and influenced directly by the results of the on-going process.

At all levels of hierarchy, growth of knowledge acts to increase the complexity and power of the variation-selection process by (1) modifying the mechanisms for variation, with resulting effects on degree of blindness and size of the field of overt variation (that is, the number of variations from which visible selection is made), and (2) expanding the processes of selection by trying out overt variations vicariously through analysis and experiment in place of direct trial in the environment. (p. 245)

As a technology matures and knowledge increases,

the body of experience about what has and hasn't worked [c.f. Petroski's emphasis on 'errors'] in the past increases, making a priori judgments easier....Experience within an established technology will for a time enhance the ability to conceive of novel features that have a chance of working; ultimately, however, the degree of novelty that is possible tends to be exhausted (in the absence of some radical input from outside, in which case the technology is superseded, in effect, by a new technology).

Vincenti alludes here to another phenomenon that appears in Section 2: *discontinuous* innovation.

Institutions also coevolve along with technologies. These institutions include "learning networks," trade associations, university research centers, and government regulatory, funding, and operating agencies. The interstate highway system provides obvious examples of public and private institutions that have emerged to support the needs of limited-access highway planning, design, construction, operation, and maintenance. In general, the overarching system of any technology and its supporting institutions is an enormously complex one.

In 1923, an anthropologist, Alfred Kroeber, drew an evolutionary tree for technology (Kroeber, 1948). Figure 1 shows how the evolutionary branches of his tree split but then re-join and fuse together as technologies merge and combine. In contrast, the tree that describes the evolution of life forms (also shown in the figure) branches like real trees, but lacks the complex re-combination and fusion characteristic of technology. This phenomenon is one that returns in the current literature--it illustrates the complexity of the "path dependent" evolutionary histories of technology development, as observed by Rosenberg, that help make technology forecasting virtually impossible. This kind of evolution is also particularly characteristic of the "complex" technologies (like ITS) that are described in more detail in Section 2. The shape of this "tree" also nicely reflects the fact that ITS draws on many technologies (communications, computers, sensors) that are developed and matured in other contexts, then fitted into ITS products and services.

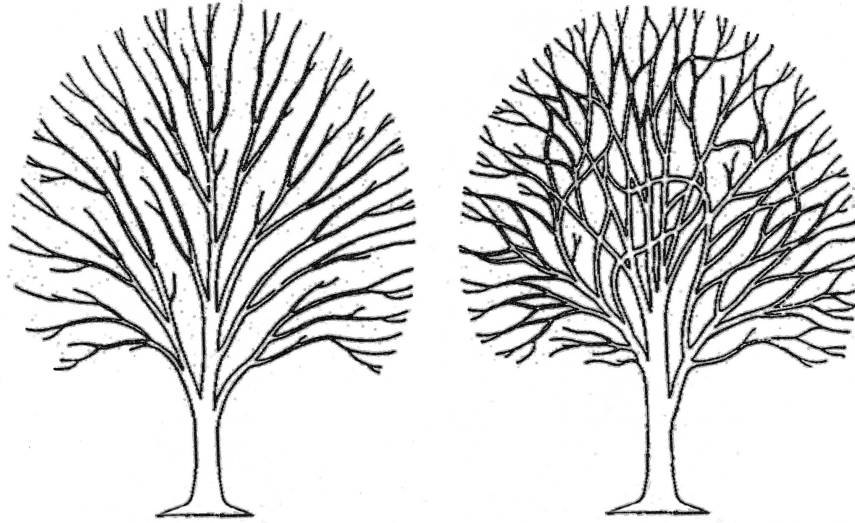


Figure 1. Family trees as depicted by anthropologist Alfred L. Kroeber. On the left is the tree of organic life, on the right the tree of technology. (Kroeber, 1948)

### 1.3 ITS Deployment

The present study has grown out of a series of PATH studies of ITS deployment. In Dahlgren et al (1996), we investigated twelve public agencies to identify factors important to successful ATMIS (Advanced Traffic Management and Traveler Information Systems) implementation. Unsurprisingly, in these case studies we found the critical factors were *need, leadership, information* and *funding*. Furthermore, in our *successful* implementation cases, funding had not been a major barrier: a good combination of the first three factors had enabled financing to be obtained from a variety of sources, as appropriate to the local conditions.

The study found that the following were characteristic features of successful implementations:

1. Large, visible needs (recognized by the community) and good opportunities for automating the management of traffic
2. The ability to build directly on existing systems (e.g. Los Angeles), or to adapt technology from a large, neighboring leader (e.g. satellite cities of Los Angeles or San Jose)
3. Respected, knowledgeable professional staff, with the energy, interest and ability for promoting new technology (see also De Blasio, 1996)

Figure 2 (Dahlgren et al, 1996) shows conceptually how the major factors influence the deployment of ITS. In the present study I focus on these specific factors: the *need*, the *leader*, *operation*, and (as the crucial connection between these two elements) *information*. The dashed line connecting “Operation” with “Information” has been added to indicate the critical feedback path not explored in the previous work, but made the central focus here, and developed in detail in Sections 2 and 3. The “operation” box has also been highlighted to reflect the added emphasis that has been attached to this phase in the current work. I hope to demonstrate that through inattention to the principles of “small, local, and private” these four critical factors (need, leader, operation, and information) are easily slighted, at great cost to the success of a deployment.

#### Some Relevant ITS Literature

At the beginning of the “modern era” of IVHS/ITS development in the late 80’s (cited above and documented in Saxton (1993) and Shladover (1993)), Garrison reviewed the then current situation in light of the history of transportation technology and the factors he saw as favorable to the initiation of a new wave of technological improvements (Garrison, 1987 a,b, 1988). Garrison’s starting point was the same one that led others to initiate Mobility



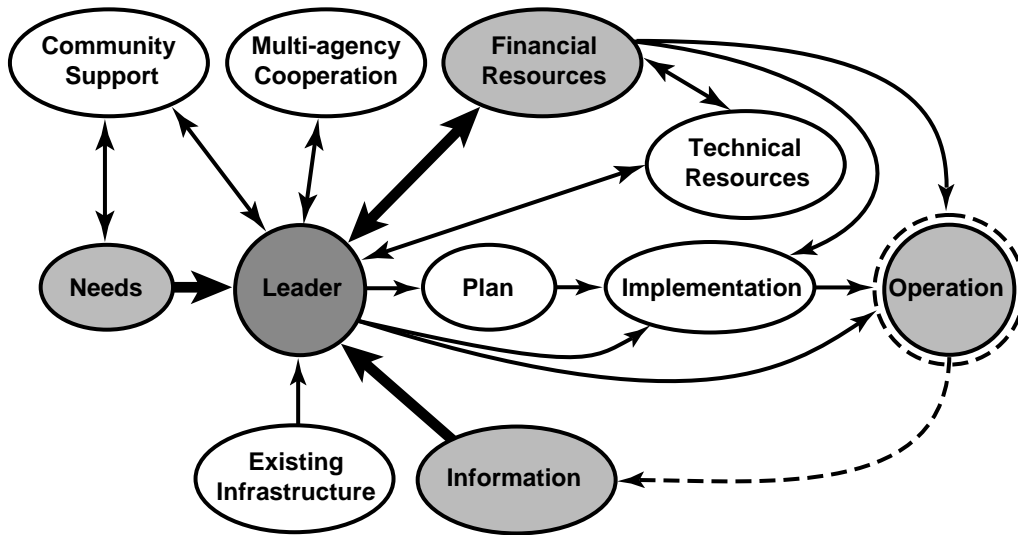


Figure 2. Requirements for successful ITS Implementation/Operations (Dahlgren 1996)

2000, the perceived need to find technological alternatives to building more roads.

Garrison takes as a starting point the S-shaped curve (he calls it the “product life cycle”) that all technology innovations follow. In (Garrison, 1997a) he gives the particularly instructive example of the “first railroad,” the Stockton and Darlington, opened in 1826 to serve coal fields that had not been accessible by existing transportation technologies. The technology-system introduced in this tramway was subsequently developed into the true railroad, based directly on embryonic features introduced here, not limited to technology, but including financial/organizational ones like the “common carrier.” Garrison identifies some features in this example that will be central to our analysis: innovation typically involves a “system,” designers and operators use testbeds to *learn by doing and using* not only about the technology but about costs, how the “system” of common carrier worked, and about customer demand (passenger service was an unexpected market that was discovered). Note that in the terminology of our title, this example is “small, local, and private.”

The Stockton and Darlington shows the importance of learning by doing and using. But it also illustrates some principles that are absent in Garrison's analysis: a) the role of learning networks, and b) the distinctions between the capacities of public and private agencies for successful innovation, and the factors that distinguish between the type innovation that each is capable of absorbing.

Klein and Sussman made an important contribution to our topic in a 1994 paper (Klein and Sussman, 1994) that has had less influence than it deserves. Their basic point is that most of ITS consists of incremental improvements for whose successful implementation local operators and users must have a much more significant role. “Relevant expertise in the operation of local transportation systems resides in operators who have implemented, operated, and maintained IVHS-type systems--and who perhaps have even terminated such systems.” They argued that more than the “outreach” program that IVHS had established, what was needed was an “intake” program in which local operators and users are the key active agents.

They make two recommendations:

1. Bring local expertise into the design process.
2. Move the system design process to the local level. Design could be effectively performed at each local implementation site, guaranteeing that local factors receive consideration. This would be achieved through an initial technology design of IVHS that is flexible, and through a willingness at the national level to allow for local design modifications.

I agree with their overall recommendations, and with much of their analysis. In addition, I draw upon new literature (including that on “learning networks” in

Section 3) to strengthen their conclusions. In addition, I add several new dimensions: a discussion of public and private roles in the light of both the character of certain ITS functions and the nature of technology change in bureaucracies. Klein and Sussman correctly stress the incremental character of many ITS *technologies*, but fail to note how in many instances radical changes are required of public agencies in terms of *tasks* performed.

Finally, I acknowledge much else in previous ITS policy recommendations that is consistent with our themes. For example, Horan (1992) called for a program that included diversified field operational tests and “an adaptive strategy which will allow IVHS to embody the best of technological developments (occurring as a result of aggressive advanced research as they unfold over time.”

What I add to this good advice is a recognition of the fundamental process for generating the real knowledge required for the evolution Horan projected. Moreover, in place of the top-down, hierarchically coordination implied by Horan, I assert that decentralized networks of local implementors and operators are critical. Furthermore, developmental and operational processes must be intimately connected to achieve the evolutionary improvements I and Horan both call for (Moore 1996).

#### 1.4 Innovation and Organizational Change

New things piece not so well; but though they help by their utility, yet they trouble by their incompatibility.

Francis Bacon, Essay IV, *Of Innovation*

Innovation is a rare event: a new technology frequently requires great organizational change to accommodate it, and this kind of change may be much more difficult to achieve than the invention of the technology itself. Many firms cannot accomplish the necessary changes, and new firms develop on the ruins of old ones, a process named and celebrated as “creative destruction” by Schumpeter.

Organizations accomplish their critical tasks in part *by resisting change*. Public agencies exemplify this rule; they evolve to minimize the costs of performing their core tasks, and thereby maximize the costs of changing them (Wilson, 1989). The implications of this phenomenon for ITS is great, as public agencies have major roles in the planning, design, funding, and operation of ITS. In Section 4 I will discuss this topic in more detail and suggest some guidelines for allocating ITS functions to public and private organizations.

The technologies that enable ITS--sensing, communications, and computation--are undergoing rapid evolution. They continue to be driven by the annual doubling of the density of integrated circuits that Gordon Moore first observed three decades ago (Schaller, 1997). The combination of improvements in many

complementary elements of ITS thus gives rise to rapidly increasing returns on investment in new technology, *when these technology elements are assembled into effective systems*. The obstacles to deployment of ITS are precisely the obstacles (technological and organizational) to the assembly of such effective systems. (Thus it is misleading to simply extrapolate the gains from the technology components into gains for transportation *systems*.) The remainder of this study details some of those obstacles and describes some policies for overcoming them.

### 1.5 Study Organization

Following this introduction, I look first in Section 2 at the basic process of technological innovation, followed in Section 3 by the closely related topic of learning networks. Section 4 summarizes the principal reasons for making projects small, local, and private. The last section presents conclusions and recommendations for further study.

As the births of living creatures at first are ill-shapen, so are all innovations, which are the births of time.

It were good therefore that men in their innovations would follow the example of time itself, which indeed innovatith greatly, but quietly and by degrees scarce to be perceived.

Francis Bacon, "Of Innovations", *Essays*

## **2. The Processes of Technological Innovation**

### 2.1 Continuous Innovation

In Section 1 I reviewed some of the literature on technological change. Here I describe a basic descriptive framework of change, as outlined by Utterback (1994). (See also Nelson 1994 a,b, Hall 1994, and Ayres 1994.) When a new technology is introduced, it is typically in multiple, imperfect forms. Many firms produce many different versions of the product, at relatively high cost; few if any of these early designs have many (or frequently any) of the salient features of the eventually successful product. As products are introduced to the market place, however, and early users acquire, use and react to them, producers gain experience in what works best. This period is marked by intense interaction by producing firms with both users and the technology. Many parallel experiments are performed by the firms who are each striving for success. (At a more detailed level, Petroski's and Vicenti's incremental design processes will be at work in perfecting technologies.) In this way, the product begins to undergo a transition to a "dominant design," taking on the shape of the final, mature product. As the dominant design emerges, the market expands, firms turn their attention to reducing manufacturing costs and product prices decline, and firms drop out of the market until only a few remain.

The whole process can be described in a familiar S-curve of the product life-cycle, as shown in Figure 3. The first phase is termed "fluid," the second "transition," and the third "specific." The dominant design that emerges during the transition period, and rules during the specific phase, possesses those features that users have judges most important. Thus, the dominant design turns out to be a standardized design achieved through the market place. I adopt this "dominant design" model of technological development as a framework for describing ITS innovation; it has been observed that this model of applies particularly well to the evolution of "systems" technologies (Nelson 1994 b), which in this literature are also variously termed "assembled" (Utterback) and "complex" (see (Kash, 1997), where there are also six contemporary case studies of innovation with corresponding, quantified S-curves for each) .

The important features of this development process are the following:

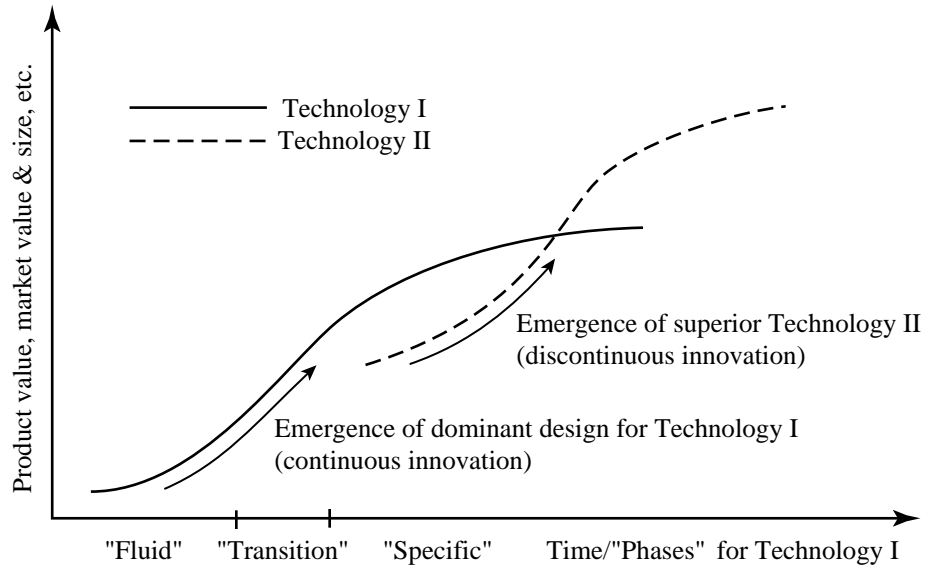


Figure 3. The Technology Innovation Processes

The early, fluid phase involves much experimentation, both in the shop or laboratory with the technology and in the market place with customers reacting to these products in actual use. At the beginning of this phase, no one knows “what” to do, or “how” to do it, and very often the real “why” (the customers’ reasons for use) is mistaken or only approximately known. This experimentation goes on in parallel, executed by many competing firms. These firms actively acquire embodied knowledge during this period. This phase is strongly characterized by intensive *learning by using*.

At the turn of the century, automobiles existed in many shapes and sizes, using different power plants (steam, electric, internal combustion engine), and had an enormous range of specific design and service features. After a transition period, however, the dominant design of the internal combustion automobile appeared, with many standard features (from rear-view mirrors to windshield wipers) determined through the test of the market and variations in the production process. Virtually all successful technologies go through such a “transition phase” to emerge with a small set of firms producing a standard design in the end. Among the critical factors influencing the successful emergence of a dominant design is “market learning” (Utterback, 1994, p.29), where producers stay very close to actual users to determine the features of products of most value to them. During the transition phase, competition shifts from a basis in differences in basic design features (as the standard design emerges) to one based on improvements in the production and marketing processes and corresponding cost reductions, with only small changes in basic design features or fundamental principles of operation.

“Market learning” during the transition phase is one of the factors most clearly absent from much ITS development. Partly as a result of over-ambitious, broad, and unrealistic projects, there is frequently little time and resources to spend on the intimate and intensive customer interaction with real products that effective market learning requires. Instead, limited (often little) testing occurs, usually augmented with surveys, and possibly focus groups, as distinctly inadequate substitutes to intensive market learning. More local and narrowly focused projects can yield more realistic market interactions. Greater involvement with the private sector will also sharpen the focus and increase the commitment to deal realistically with customers.

Also largely absent from past ITS development has been the large-scale, active participation of local operators called for by Klein and Sussman (1994) and Rowe (1993). This involvement not only facilitates market learning, but also develops necessary knowledge about deployment and operation of technology in the local transportation, institutional, financial, and political setting. As Rowe (1995) has pointed out, local government transportation agencies are intimately involved in critical, foundational functions of traffic management and traffic information generation (local agencies must collect local information!); they

must also be involved in the development of design standards and guidelines on operations and maintenance.

Operation and maintenance are good examples of functions that are difficult to abstract and extract from their specific local operational context. The criticality of understanding operation and maintenance and their costs are attested to by many experienced operators, e.g. by Rowe (1993), Delgado (1996), and Paral (1996). Only by doing (i.e. operating ITS systems) can local agencies assess these costs and discover ways to improve the efficiency of operation and maintenance functions. If higher level performance information is difficult for current planners to assess, this critical, foundational data on operational and maintenance costs is virtually inaccessible to them at the present time.

Successful learning by doing is vividly exemplified in the way that Intel has integrated technology development and manufacturing.

With a product as complex as semiconductors, it is a tremendous advantage to have a production line that can be used as a base for perturbations, introducing bypasses, adding steps...Locating development and manufacturing together allows Intel to explore variations on its existing technologies very efficiently.

(Moore 1996)

This integrated development process and production line has much in common with the Southern California Testbed, operated by the University of California, Irvine, in partnership with Caltrans, the UC PATH Program, local cities, Orange County, and private industry (UC Irvine 1997). The idea is to use real transportation systems and operating agencies to develop and test new technology. A major difference with the Intel case, however, is the more complex institutional setting and the more diffused ownership of operational impacts. Nevertheless, the Testbed concept appears to be a viable approach to achieving the desirable connection between development and operations.

In the development of any modern technology, there will be a “complex web of interrelated events” taking place among different kinds of firms. Utterback (1994) gives the example of integrated circuit producers, software companies, and disk drive companies working together to continue innovations in PC's. In the ITS world one could think analogously about the importance of GIS firms, traffic information providers, traffic engineers, and systems integrators all working together to engage the market and develop new products (see, e.g., a later example involving TravInfo contractors joining together to make new products).

Also note that an effective transition stage requires many firms, performing many different market experiments. Again, real, *local* projects will tend to better support the requisite number of firms during this stage.



Nelson (1994 a) discusses transition phase processes in some detail. The dominant design need not be simply a “best” design, since a final “standard” configuration may also be influenced by chance as well as by industry agreement and/or government regulatory action. Although these processes are extremely difficult to forecast, giving rise to very complex “path dependencies” (Rosenberg 1994), nevertheless, a dominant, underlying driving force is still learning by doing and using .

During this transition phase, as a standard design emerges triumphant, and many firms fall by the wayside, simultaneously the market increases. Finally, in the specific phase, a single design is produced by a few firms at low cost in large quantities.

In the surface transportation world, an S-curve would accurately represent the growth of private automobile and commercial trucking transportation over the twentieth century: First a fluid phase in the early part of the century, with lots of small, local innovations in streets and roads; next a transition phase from the thirties through the post-war years, culminating in the emergence of the “standard design” of the interstate highway system (a standard in this case imposed by the federal government rather than the market place, but still emerging rather naturally as in the Utterback model from a period of much varied local experimentation); and finally a “specific” phase of steadily decreasing marginal improvements due to cost, financial, and environmental effects, and compounded by the particular growth of travel in the 70’s and 80’s due substantially to the expansion of women in the workplace. Note also that vehicle technology and fuels, the fueling system, as well as numerous public and private institutions all co-evolved along with the road system--an important point that I will return to later. It is in fact the perception of the flattening portion of this curve that led to the initiation of the ITS program in the late 80’s. At its most ambitious, ITS proposed essentially to move us to a new paradigm for surface transportation, one that would be described by a new S-curve, as shown in Fig. 3, leading us to a set of innovations, culminating in highway automation.

## 2.2 Discontinuous Innovation

To describe this kind of transition to a qualitatively different technology, I need a new model. The first model described how innovation occurs as a *continuous, incremental* process. It didn’t attempt to describe how innovation begins, or equivalently, how a transition occurs from one technology to another. I now consider this question of *discontinuous* innovation, again following Utterback. (I defer the question of which ITS technologies represent continuous, incremental innovation and which ones represent discontinuous, radical innovation. Klein and Sussman (1994) argue that near-term ITS is incremental. I disagree and think there are elements of both types of innovation in most ITS systems, and return to this subject later.)

It would be madness and inconsistency to suppose that things which have never yet been performed can be performed without employing some hitherto untried means.

Francis Bacon, *Novum Organum*

Discontinuous innovation occurs when the basic technology for accomplishing a function changes. An example is the replacement of the mechanical/electrical typewriter by the personal computer. (I consider the transition between these two kinds of writing machines to have been of the continuous type.) Here the technologies are fundamentally different, and the products are also substantially different in functionality, though they are both “writing machines.” (It’s interesting to note that, just as in the ITS case, some but by no means all of the improvements in productivity in this transition are readily quantifiable. Just as the personal computer has enlarged the flexibility and the rapidity with which one can react to change and new information, so many ITS services enlarge our mobility and ability to respond to change, with benefits that are not easily accounted for by time savings, for example.) In this case, most old firms are no longer making writing machines, although one (IBM) is, and many entirely new firms (Microsoft, Intel) are dominant in the new business.

Utterback defines three critical attributes of discontinuous innovation. They concern whether the technology is:

1. assembled or non-assembled
2. a market substitute or market enlarger
3. competence-enhancing or competence destroying

*The most disruptive innovations are those that are assembled, market enlarging and competence destroying.* Such innovations virtually always originate outside the industry producing the current dominant technology. I have not examined ITS technologies in any detail on these dimensions; however, a cursory review suggests the following:

1. ITS is distinctly an “assembled” product, involving the integration of many specific technologies and institutions, and in contrast to non-assembled products like chemicals. (“Assembled” products are similar to Kash’s “complex” technologies, which are the focus of Section 4, where the role of learning networks is identified in the innovation process.)
2. ITS appears to have elements of both substitution and complementarity, depending on the specific service.

3. For public agencies especially, ITS has elements of “competence destruction.”

Our tentative conclusion is that ITS (even in the near-term forms studied here) tends to exhibit these three qualities, and is therefore likely to have much in common with typical discontinuous innovations with large disruptive effects. (An interesting study would be to systematically examine ITS technologies, products and services on these dimensions in order to classify them on a scale of incremental-discontinuous innovation.)

Taking this tentative conclusion as a working hypothesis, now examine the ITS “industry” according to Utterback’s analysis of firms engaged in discontinuous innovation: Innovation in ITS must therefore inevitably utilize outside sources, i.e. firms and individuals who have not been players in the traditional surface transportation industry. The detailed arguments for this phenomenon are outlined in Utterback (pp. 160 ff.) and Nelson (1994 a), where he points out that core capabilities must evolve along with the dominant design--thus the firm possessing the old dominant design will by its nature have only those competencies necessary for the old design, and therefore not all the ones required for the next one.

Of course, the need for new industrial participants in ITS is not a novel observation--essentially this is the rationale for promoting the involvement of the communication, aerospace and defense industry in ITS at the beginning of this decade. However, in spite of this early recognition of this need, the integration of these new players has not been as rapid as originally expected.

One obvious reason for the slow progress of innovation in ITS by means of these “outsider” firms is that surface transportation remains largely a public monopoly, and thus Utterback’s analysis does not apply. Public transportation agencies do not face new competitors who are introducing new technology, and thus are not driven to innovate by the acute prodding of the market place. This of course is an important rationale for the frequent calls for public-private partnerships. Nevertheless, in spite of repeated calls for such partnerships, innovation by means of this outsider group has been slow. For some insights into how existing firms can better accommodate discontinuous innovation, I first return to Utterback, and then combine his insights with Wilson (1989), regarding public agencies.

### 2.3 How Existing Organizations Accommodate Discontinuous Innovation

Utterback identifies three strategies by which existing firms successfully participate in radical innovation. They may:

1. set up dedicated new units

2. form alliances with small, “outsider” firms
3. build on existing competencies

Each of these approaches is a way of overcoming the large obstacles to achieving radical change inherent to any existing organization.

In the first approach, the organization attempts to create an “outsider” organization within itself. This is a fairly standard approach, and has been used successfully by some organizations. The Lockheed “skunkworks” is one successful variant on this theme, where a unit is given substantial independence and an explicit charter to innovate. There are also, however, examples of failure for this approach, Xerox PARC being perhaps the most famous instance, made particularly notorious by the fact that the parent organization was unable to exploit discoveries at PARC, while its competitors were (Smith 1988). There are no easy answers here: As Wilson (1989) points out, organizations that must readily generate innovative ideas tend to be most loosely and decentrally organized; hence they find it most difficult to implement the new ideas. Conversely, organizations that can most readily implement novel ideas--through their hierarchical organizational structure--find it most difficult to generate them.

Even at Intel, where there is an intimate and successful integration of development and manufacturing, a separate organization is set up to explore radically new technologies (Moore 1996, p. 168).

A related feature of some public transportation agencies worth study is their use of existing regional units. For example, Caltrans has twelve regional districts. Each district is responsible for managing state transportation construction, maintenance and operations in their own area, and districts have tended to have substantial autonomy in accomplishing those core missions, in ways that fit their particular regional needs and constraints. There has been a trend in recent years to standardize operations across these district offices. No doubt much standardization will be of value, e.g. for improving communication among offices and other agencies, and for obtaining less expensive procurements. On the other hand, it appears that the diversity among the districts has beneficial effects in encouraging local innovation, e.g. District 7’s Smart Corridor Project, and District 12’s collaboration with other agencies and universities in the Southern California Testbed. The results of this diversity are successes (and failures) that can be copied (or avoided) by other districts, as their needs evolve. Thus, a large transportation agency like Caltrans may find it valuable to preserve and even nurture some diversity among its district offices.

The second approach is in fact similar to the first, in that it attempts to obtain new knowledge and skills through cooperation with another firm that has already developed them. (The two approaches may be very close indeed, as

an important way of establishing a “new unit” is to buy one.) As discussed in Section 3, the question of cooperation and communication among networks of organizational units is central to the effectiveness of innovation in complex technologies, and this appears also to be true for internal integration within an organization (compare PARC with Intel, for example (Moore 1996)).

An effective ITS example of this approach can be found in the TravInfo Field Operational Test in the San Francisco Bay Area. This project set out to develop a central, open-access traveler information data base, and by making this information freely available to independent service providers, stimulate the private traveler information business. Although the project has not achieved this goal, they have developed a Traffic Information Center (TIC) that is operated by a private contractor, Metro Networks. While this development was intended only as a means to a larger end, it turns out to be a nice example of the second strategy.

The managing partners of the TravInfo project are Metropolitan Transportation Commission (MTC), California Department of Transportation (Caltrans), and the California Highway Patrol (CHP), with the MTC as program manager. The MTC has no experience in the packaging and communication of traffic information directly to the traveling public, while Caltrans and CHP have limited experience. Thus, when it came to developing the TIC, TravInfo sought a private contractor through a competitive bidding process. The successful bidder was Metro Networks.

The results of the first year of operation of the TIC have demonstrated the effectiveness of this “partnership.” (Miller, 1998) Metro Networks has brought distinct and unique knowledge to the operation, e.g. how to extract useful information for drivers from incomplete information (the data sources in TravInfo are less comprehensive than originally planned), how to package that information for maximum utility, how to best deal with the media, and how to quickly adapt to work in a new environment, with new partners, under new constraints and requirements. It can be hypothesized that apparent success here is a product of specific domain knowledge (learned while doing their normal business of producing radio and television traffic reports), together with the flexibility and incentives of an aggressive private business. It also should be emphasized here that this achievement was not one originally projected as a TravInfo goal, nor did the knowledge base of Metro Networks ever appear understood or particularly valued by the planners and partners in the project (personal observations, 1993-97).

Intimately known by practitioners, the very existence of embodied knowledge is often ignored by outsiders, even unsuspected by them.

...the production of knowledge is contextual, burdened with the specific circumstances in which it occurs. The communication of knowledge from one context to another, from one individual, firm, industry or country to another, is not unproblematic...

...individuals accrue advantages over all others in that they have access to unique information that can be put to beneficial use, but only if the decisions depending on it are left to specific individuals or are made with their active co-operation.

(Lundgen, 1995)

The returns are significant from the interaction of agents in the production of knowledge in specific production settings, as illustrated in this ITS example: The mix of private contractors involved in the TravInfo project has also led to the development of new products, e.g. ETAK, Gardner Rowe Consultants, and Metro Networks collaborated on the development of a new workstation for traffic information processing. Here is an example of how a project that involved “doing” a real task (implementing and operating a TIC) led to the formation of a network of relationships that in turn led to the development of new technology. Again, this particular result was unforeseen in the original TravInfo plans.

A negative instance of this principle at work can also be found in TravInfo, as reported by Hall (1998). The MTC found itself in the position of overseeing a technical contract for the development of the TIC system software, without having prior experience in this area. At least in part for this reason, this development project has suffered difficulties. (See Section 3 for a discussion of other possible reasons for these problems.)

A successful example of the privatization of a Traffic Operations Center is reported by Yermack (1996). Parsons Brinkerhoff has provided operations services for the INFORM system in New York State. Yermack highlights the advantages to the public of acquiring expertise otherwise unavailable; he also identifies some of the management challenges.

In the third strategy for achieving radical innovation, the existing organization examines its existing competencies to find those upon which skills relevant to the new dominant design can be built. This approach appears particularly pertinent to public agencies, where the problems of radical organizational change are notoriously great. I start by summarizing an important framework for understanding innovation in a bureaucracy (Wilson, 1989).

## 2.4 Innovation in Bureaucracies

In civil matters even a change for the better is suspected on account of the commotion it occasions, for civil government is supported by authority, unanimity, fame, and public opinion, and not by demonstration.

Francis Bacon, *Novum Organum*

We ought not to be surprised that organizations resist innovation. They are supposed to resist it. The reason an organization is created is in large part to replace the uncertain expectations and haphazard activities of voluntary endeavors with the stability and routine of organized relationships. The standard operating procedure (SOP) is not the enemy of organization; it is the essence of organization.

Wilson, 1989 (p.221)

This stability of routine tends to be particularly strong in public agencies where demands for equity are readily enforced. Clearly, this is the case with transportation agencies. What can such agencies do to overcome these rigidities, and to facilitate ITS innovation?

Organizations are largely defined through their *critical tasks*. Moreover, government agencies are more sharply defined by these tasks than by their announced “goals,” which are apt to be defined in general, vague or even contradictory terms. Critical tasks are “those behaviors which, if successfully performed by key organizational members, would enable the organization to manage its critical environmental problem.” (p.25) Thus the resistance to change in an organization is intimately connected with its need to maintain critical tasks.

However, while changes requiring critical task redefinition will be resisted (or at minimum not pursued with enthusiasm), *changes that assist in the performance of existing tasks will tend to be welcomed\**. Thus new technology that permits an organization to perform its critical tasks more effectively can appear attractive and be adopted relatively quickly and easily. Traffic engineering departments in city and state agencies have a well-understood and articulated responsibility for facilitating the efficient and safe movement of traffic; hence the adoption of new technology that helps them do *these jobs* better tends to be welcomed, provided of course that various constraints can be satisfied (cost-effectiveness, available funding, technical knowledge, perceived external costs, etc.). Thus, the Los Angeles Department of Transportation, , early on in the 70’s, long before the IVHS/ITS national program was born, began to develop traffic control systems (in their ATISAC system) that relied on (then) modern computer and communication technology. While they had the benefit of possessing the significant necessary ingredients for successful deployment, as identified in Figure 2, and in particular possessed a knowledgeable and energetic leader in

Ed Rowe, nevertheless, a crucial necessary ingredient in their success was the simple fact that the tasks assisted by the new technology were *their core tasks*.

\* Gordon Moore (1996) cites an interesting variant on this principle. In their experience at Intel, they found that the more technically competent a receiving organization becomes, the more difficult it is to transfer technology to it. For this reason, Fairchild, when it had developed a technically strong manufacturing organization, was unable to accept new technology from their [separate] R&D Lab. "Production, it seemed, had to kill a technology and reinvent it in order to get it to manufacturing."

Many new ITS functions, however, do not simply enhance existing tasks of public transportation agencies, but in fact create new ones. Examples are: traveler information as a revenue-generating service, commercial vehicle services, many new emergency response services, "inter-modal" services," virtually any service requiring inter-agency coordination (even among branches within existing public agencies), and road pricing (where the pricing involves new kinds of facilities or new schemes, such as congestion pricing). Hence it is not surprising that the implementation of these new tasks within existing agencies presents great challenges, and requires not only technical skill but significant organizational strategic insights and abilities.

One way to overcome these challenges within a public agency is to go outside the agency for private-sector partners. This strategy is the second one of the list of three in Section 2.3, and was discussed earlier. In the context of the current discussion, however, I add the third element, building on core competencies. Thus a public agency, when confronted with producing a new service that does not map neatly onto their existing core tasks, can identify those tasks that do not match, and seek them in private partners, while retaining those tasks that do fit their current competencies. The State Route 91 Variable Toll Express Lane Facility (SR 91) is a good example of this kind of project.

A group of private partners included Cofiroute Corporation, the California subsidiary of Compagnie Financiere et Industrielle des Autoroutes, and Kiewit SR 91. Cofiroute has extensive experience in financing, building, and operating private toll roads. Kiewit is in the business of electronic toll collection. In the overall partnership, Caltrans participated significantly in early planning and in managing the complex process for obtaining the necessary environmental and other approvals. These tasks fit exactly Caltrans core competencies; furthermore, Caltrans, by doing this work at the early stage of project development, was assuming the larger risk that was appropriate for a large government agency, but that could not readily be assumed by private companies. The apparent success of this project appears to be due in no small part to this nice allocation of tasks to each partner, according to its proven, core competencies.



The literature on “innovation communities” (Lynn, 1996) reinforces the importance of this privatization strategy for ITS:

...incumbent firms are less competent than new entrants when it comes to introducing “architectural innovations” (i.e. those that change the ways in which the components of a product are integrated into a system). The reason is that the architectural knowledge developed by incumbent firms is accompanied by information filters and information channels that facilitate the incremental development of product components, but make it harder to develop or introduce new ways of using the components.

New technologies that are not particularly radical from the technical standpoint may pose challenges to institutional arrangements because commercialization may depend on technological complementarities and require the integration of diverse elements of information, knowledge and skill, [as well as] formerly unassociated persons, pieces of equipment, and financial agreements.

(p. 99)

An example of successful entrepreneurship in a previously public industry is offered by the Ocean State Power Plant (Weiner, 1996). This is a 450 megawatt gas-fired power plant in Rhode Island, one of the first in America developed by an independent, non-utility firm. It was a notable success in utilizing a new high-efficiency gas turbine technology, and in achieving low environmental impacts. Weiner attributed success to a number of factors that seemed also to be present in the SR 91 case: 1. attending carefully to regulatory and environmental issues, 2. assigning strong, complementary roles to each partner (“Each player was selected so that the project would solve a major issue for each of them.”), and 3. strong, active management.

Other examples of partnerships based on the exploitation of complementary competencies are shared-resource partnerships for telecommunications. (Jakubiak, 1997) State transportation agencies control limited-access rights of way for communication infrastructure on their roadway system; however, they are severely limited in capital resources for the installation of telecommunication lines for ITS purposes, and they responsibility for maintaining safety on their rights of way. In addition, modern communication infrastructure tends, in its most economically efficient implementations, to have much greater capacity than needed for highway applications alone. On the other side, communication firms have the technology and access to financing and to broader markets. Hence, transportation agencies are inventing ways to form partnerships that combine their property access and control and their knowledge of (and responsibility for) safety requirements with the technology and funding sources of the telecommunication industry, yielding ITS communications services for their states, together with broader social communication benefits.

## 2.5 The Evolution of Complementary Technologies and Supporting Institutions

No man shall seweth a piece of new cloth on an old garment: else the new piece that filled it up taketh away from the old, and the rent is made worse. And no man putteth new wine into old bottles; also the new wine doth burst the bottles, and the wine is spilled, and the bottles will be marred: but new wine must be put into new bottles.

New Testament, Mark 2:21, 22

I conclude this review of technology innovation processes by briefly discussing how complementary technologies and supporting institutions evolve along with a primary technology. Earlier, in describing the continuous innovation process by the S-curve of Fig. 3, I emphasized the development of *technology* and *product*. However, simultaneously, new *institutions* also evolve (Nelson 1994 b), along with complementary products. These new institutions and products include:

### 1) scientific fields

As Rosenberg (1994) points out, scientific principles usually cannot identify in advance the performance characteristics of new technology--thus technology often leads the science. In turn, then, a new scientific field will help gain better understanding and consequently facilitate further development. Possible "new science" induced by ITS experiences include improved traffic models and simulations.

### 2) legal structures

Property rights are often the focus of conflict in new technologies, especially with the involvement of public funding. Liability questions also commonly arise. Such questions arise frequently with early ITS implementations or plans.

### 3) government agencies and policies

The existing capacities and practices of public transportation agencies are being strained by ITS (Horan, 1995). Inappropriate government procurement policies have been major causes of project delay (deBlasio, 1996). In addition, many ITS functions call for unprecedented degrees of coordination among public agencies.

#### 4) infrastructure

In transportation, infrastructure is of course explicitly recognized as part of the technology system. One of the novel features of ITS, however, is that a *communications* infrastructure is required for the first time to be integrated with the “conventional” transportation infrastructure.

#### 5) formal and informal support organizations and networks

These include professional, industrial, research, and educational institutions. I take up this topic in detail in the next section.

#### 6 ) new products and technologies

Many of these features are well illustrated by the co-evolution of the multiple technologies and institutions that constitute the national interstate highway system. Automobiles, the roadway network (local streets, arterials, and freeways), and service functions such as gas stations and motels, co-evolved to fit each other in technical characteristics as well as in patterns of use. At the same time, on local, state, and federal levels, legislation and government institutions evolved to plan, fund, build, operate, maintain, and regulate these systems. This process took some thirty years to mature (from the 30's to the 60's), with some significant regulatory features (in the realms of environment and safety) continuing to evolve to the present time. At a deeper level, the evolution of automobile technology is also intimately connected with the evolution of urban form and function and with broader aspects of the culture (see Wachs and Crawford (1992) and Flink (1988).) *Related technologies and institutions evolve through an often slow process of doing and using.*

The tree of evolution of human artifacts in Fig. 1 illustrates nicely this kind of intertwined evolution of technology and institutions. (ITS especially depends on technologies that evolve first along other, independent branches, then join and support ITS branches after they are matured.) The complexity of this dynamic further shows why it is extremely difficult to *plan and manage it as a process*, and why it can only be accomplished (without great risk) through learning by doing and using, in many small, interrelated efforts, in parallel and in series, with many *small* failures along the line (Petroski, 1994).

Massive, unique projects, funded by distant government bureaucracies, have great propensity for (great) failure (see, e.g. (Cohen, 1991) and (Hall, 1982)). As pointed out by Wilson (p.229),

...any top-down change is risky. When government executives are the source of a change, they are likely to overestimate its benefits and underestimate its costs. This is true not only because executives lack the

detailed and specialized knowledge possessed by operators and lower-level managers, but also because of the incentives operating on the executives.

It is particularly important, then, for the development of complex systems like ITS not to proceed in a centrally planned, distantly-funded fashion. It is better to rely to the extent possible on internal, “naturally” evolving supporting and learning structures. The next section takes up this subject in more detail.

### 3. Learning Networks

I will impart unto thee...the true state of *Salomon's House*...whose end is the knowledge of Causes, and secret motions of things; and the enlarging of the bounds of Human Empire, to the effecting of all things possible...

We have twelve fellows that sail into foreign countries...who bring us the books, and abstracts, and patterns of experiments of all other parts...

We have three that collect the experiments which are in all the books...

We have three that draw the experiments of all mechanical arts; and also of liberal sciences; and also of practices which are not brought into arts...

We have three that try new experiments, such as themselves think good...

We have three that draw the experiments of the former four into titles and tables, to give the better light for the drawing of observations and axioms out of them...

We have three that bend themselves, looking into the experiments of their fellows, and cast about how to draw out of them things of use and practice for man's life, and knowledge...

Then after divers meetings and consults of our whole number, to consider of the former labours and collections, we have three that take care, out of them, to direct new experiments, of a higher light, more penetrating into nature than the former...

We have three others that do execute the experiments so directed, and report them...

We have consultations, which of the inventions and experiences...shall be published, and which not...

Lastly, we have circuits or visits of divers principal cities of the kingdom; where, as it cometh to pass, we do publish such new profitable inventions as we think good.

Francis Bacon, *New Atlantis*, 1624

In previous sections, I described how technological innovation involves the acquisition of knowledge that can only be obtained through learning by doing and using: “doing” through development and production and “using” through marketing and customer experiences . I emphasized how much of this knowledge is implicitly embodied in the details of technological processes, and how difficult it is to forecast either technical or market properties by “scientific” methods in advance of actual use. I alluded to the important role of supporting organizational structures; in this section I examine this role in more detail.

In “Technology Policy in the 21st Century: How Will We Adapt to Complexity?”, Don Kash and Robert Rycroft review six case studies\* of recent technology innovation. They assert that “complex” technologies are becoming increasingly important economically and that these complexities increase the normal amount of uncertainty involved in innovation; they go on to analyze in some detail the organizational processes necessary for the innovation of these technologies (Kash and Rycroft, 1997). I follow their development closely.

A complex technology is one that cannot be “understood entirely by an individual expert and accurately communicated among experts across time and distance.” Complex technologies depend more on group-based, tacit knowledge than simple technologies. Examples of the former are computers and communications, of the latter, industrial chemicals. Thus, complex technologies have many of the features of Utterback’s “assembled” technologies, and appear to be typical of ITS functions. I note that while ITS systems may have substantial technical complexity, much of their complexity arises from their *interacting* technologies and from their frequently extremely intricate mixture of diverse agents for planning, building, operating, maintaining, regulating, and using.

...most innovation involves the interaction of a technological community and a technological trajectory...the members of the community share a common, experience-based, body of heuristics (i.e., how to do things, where to search) and have broad agreement on the key technological and organizational opportunities and obstacles likely to be encountered in the further evolution of the trajectory. The community will have some consensus on how to advance the state of the art.

\* The case studies were: Varian radiation therapy linear accelerator, HP ultra-sound cardio-imaging, micro floppy disk drives, compact disks, turbine blades, and the microprocessor.

As technology innovation proceeds, this community will come to include more than one network, in its mature phases encompassing “large constellations or complexes of networks or even broad sets of social institutions (e.g. education systems, legal regimes) at the national level.” The national highway system and associated institutions, firms, associations, agencies, and educational functions represent one such “network of networks.”

In each technological community there was a shared sense of what incremental innovations would come next, and there was always uncertainty about how it would be accomplished. The shared sense of what comes next is derived from accumulated experience--much of it manifested in tacit knowledge. Since the innovation of complex technologies defies explicit understanding, there is no theory from which the next incremental innovations can be deduced. And since views of what comes next are to some degree experientially derived and tacitly manifested, they may change with the experience of each innovation.

The capabilities for technological innovation are distributed throughout a *network* of participants, involving both *core* and *complementary* knowledge assets. In each of the six case studies, core capabilities included the capacity for systems integration. Complementary assets are held by suppliers and various specialized service groups, and are connected to the holders of core capabilities through the network. A particular strength of these networks is to “rapidly access and decouple from sources of knowledge, usually complementary assets, as innovation needs change.”

Success requires that networks self-organize themselves in ways that enable them to co-evolve with technologies. Only self-organization and coevolution offer the structural capacity to flexibly and intimately connect diverse technical expertise (e.g., engineering design, prototype development) with diverse capacities (e.g., political, legal, or financial skills).

In each of Kash and Rycroft’s case studies, they found that innovation required the ability to link “the technical abilities of people located predominantly in corporations, universities, and government laboratories with social skills typically found in government agencies, consulting firms, and not-for-profit organizations (e.g., think tanks, professional associations).

They find that network forms are also evolving from formal-legal, arms-length relationships to ones based on shared needs and trust and reciprocity. The key to the value of trust lies in the nature of complex technology knowledge. By its tacit nature it is difficult to communicate such knowledge completely; thus personal trust is an important basis for its shared use.

...trust is especially important in the arena of complex technologies because innovation is carried out without understanding. If you can’t understand what is taking place, trust takes on special importance. The substitution of trust for understanding is at the heart of the intimate, long-term, inter-organizational arrangements that increasingly characterize

network relationships. As the innovation benefits of trust are realized, the confidence in and intimacy of network relationships increases.

Similarly, in the absence of trust, the effectiveness of a network declines. In the TravInfo project, for example, trust between the manager of the program, MTC, and the implementor of the system software, TRW, declined precipitously during the first years of operation (Hall 1998). By falling back on narrowly interpreted legal obligations, work proceeded extremely slowly, with negative consequences for the immediate larger project; at the same time, no “network relationships” were established to support future work, or permit the two parties to share useful information informally. In contrast, two of the participants in the TravInfo project, Etak and Metro Networks, through their active, though at the time non-contractual, participation in the project, established a trusting, complementary relationship that led to the development of a new business product that could not have been produced by either one independently, as well, presumably, to a relationship where the principles can informally share information of mutual value. Again benefit accrued from *doing* things in which each party had core competencies; in contrast, in the case of MTC and TRW, both parties were new to the business of the project (for the one, managing a large software development project, for the other, developing traffic information system software).

ITS is an archetypical “complex technology” because of the *diversity of knowledge required for its implementation, and because of the dispersion of that knowledge among many different organizations, of diverse types*. Hence it is particularly important for all participants in ITS to recognize the primary importance of learning networks, and to make the facilitation of such networks of the highest priority. At the same time, it is equally important to recognize that learning in a network can only occur if its members are *doing* and *using*. Thus, organizations like ITSA and programs like the USDA Peer-to-Peer Program (USDOT, 1997) can be extremely important, but only if real developmental activities are underway and building experiences and knowledge that can be shared.

In a study of technology innovation in the transit industry, Hansen (1994) identifies consultants as influential in agency decisions in adopting new technology. Presumably these are consultants with whom the agencies have established a relationship of trust. Hansen goes on to recommend that Caltrans establish an intensive assistance program with California transit agencies. One can imagine here Caltrans helping to provide the network linkages among those transit agencies engaged in active technology tests (as Hansen reports in detail). Similar linkages may also help local transportation agencies select appropriate contractors. At present, these agencies have a difficult task in deciding among diverse contractors (e.g. traditional transportation consultants and aerospace/defense contractors), in the absence of knowledge on their



capabilities and past performance, especially since these agencies do not have relevant technical knowledge. (Paral 1996)

Because ITS is a data and communications-intensive industry, it should be relatively natural to facilitate the development of ITS innovation networks. Clearly, as in the case of other industries, ITS is making extensive use of the internet for communications among organizations and individuals. Specifically, by facilitating relationships among geographically far-flung individuals, the internet may mitigate one of the current challenges to establishing ITS, the fact of few, dispersed active experiences with ITS implementations. There is no geographically compact region like Silicon Valley, where the web of formal and informal relationships (amplified by the active movement of personnel among organizations) is a significant factor in the ability of its industries to rapidly innovate. (Saxanian, 1990) The intertwined networks of social, professional, and commercial relationships “transcends inter-firm rivalries.”

In the process, technical and market information diffuses rapidly within regional networks which combine and recombine existing skill, technology, know-how, and experience. (Hansen et al, 1992)

There are numerous cases of internet-based systems for communicating ITS information. One of the best examples of internet-based “learning networks” is the LEAP (Learning from Evaluation and Analysis of Performance) system of the PATH Program. (Dahlgren, 1997) The purpose of this system is to identify projects that have generated and reported results in terms of costs and benefits. The system organizes these systems by service, and summarizes results within a common reporting framework. Interested parties can access original documents or contact the subject project personnel for more information. An important feature of LEAP is its emphasis on actual operating experience.

Establishing a purely *formal* web of communications by itself is unlikely to be sufficient. Furthermore, formal communications from government executives and program managers can be self-serving and misleading. (LEAP addresses this problem by having an objective third party collect and organize the information; nevertheless, it is difficult to filter out all the exaggerations and inaccuracies from a large number of studies.) Active learning about complex technologies (including information about technology failures and bad contractor performance) best exploits trusting, cooperative, intimate relationships. These relationships cannot easily be established, however, without reciprocity. (Hansen et al, 1992; Dickson, 1996) And reciprocity can only exist where each side has something to give to the other, that is each side has some competencies earned through doing and using. Furthermore, Dickson (1996) asserts that *personal experience* increases the perceived value of information.

An example of an ITS network that partially achieves the goals of these learning networks can be found in (Schnur, 1996). The authors describe how an Early Deployment Plan (EDP) was developed for the San Francisco Bay Area, and the critical role played in this process of building partnerships among agencies that own and operate portions of the Bay Area's transportation system. However, this activity may serve to introduce the ideas of ITS to the various members, and to introduce potential partners to each other, it also inevitably lacks the critical element of substantial ITS knowledge sharing. One Bay Area community (San Jose) has a good knowledge base earned through its own development of a modern traffic management system, and at least one other community has a traffic engineer with extensive ITS development experience (Don Dey in the City of Menlo Park), but otherwise there is little experience with ITS in the Bay Area. Beyond the instances cited, the majority of the experience rests in the TravInfo Field Operational Test, which has failed to produce the results (and hence much of the experience base) that was originally expected (Hall, 1998). One suspects that a more natural network of ITS implementors may grow up around the existing center of ITS development in San Jose, rather than through the kind of top-down process of (Schnur, 1996); in fact plans are proceeding there with San Jose and adjacent communities working to extend San Jose's system into the surrounding region.

As Klein and Sussman (1994) pointed out, a key to developing effective learning networks is to involve local operators who have real experience.

Kash and Rycroft cite SEMATECH as a successful example of a network initiated by industry but launched with federal support. Among other functions, SEMATECH provides updated roadmaps to help guide federal research, and corresponding "benchmarks" against which industry progress can be compared (Moore, 1996). A similar function in the ITS world is provided by ITSA and its state chapters, linking government agencies and industry in support of ITS innovation.

However, despite the obvious similarities between SEMATECH and ITSA, there are also some major differences. First, SEMATECH was developed by a mature industry with extensive experience and active, dynamic operations; in contrast, ITS has remained an industry in formation in most areas. Second, SEMATECH has been driven by the active leaders of an entirely private and relatively homogeneous industry, while ITSA has necessarily been composed of a diverse mixture of public and private agencies, with the private members themselves representing quite diverse interests and types of activities and customers (ranging from car manufacturers to communications technology firms to transportation consultants and defense system integrators). Finally, SEMATECH's latest roadmap (Microtech 2000) has incorporated quantitative effectiveness measures, specifically cost per square centimeter, as a benchmark against which future technology is to be compared; while ITS strategic plans contain performance projections, they are typically more

“visionary,” and inevitably less susceptible to verification (and more amenable to executive spin-doctoring) than the SEMATECH targets. (I come back to this important topic in the concluding section.)

In the case of a single large transportation project with substantial technology innovation, Hickman (1994) observed that serious problems occurred in the early deployment of BART because the people with relevant technical knowledge were cut off from the political decision makers.

Robert Pool (1977) describes how single organizations use active and intensive communication and learning to deal with extremely demanding performance requirements. Organizations such as the Diablo Canyon nuclear power plant use “active, probing learning” to link operating personnel to facilitate constant alertness and continual improvements. Parallel with a hierarchical set of rules and regulations is a dynamic and much more decentralized learning structure.

Another factor inhibiting the flow of ITS information is the proprietary nature of many of the systems being developed and deployed. Increased use of standards will facilitate not only the operational interconnections that is one of the ostensible goals of such standards, but also the growth of learning networks.

There is a growing literature on the subject of network organizations, much of it relevant to those in the ITS community interested in institutional issues and government policy. See, e.g. (Lorenzoni, 1995) for options for mixes of public and private participation, (Hagedorn, 1990) for the variety of inter-firm cooperation, (Baba, 1993) for a case study of network innovation on the VCR, and the notion of “systemic innovations”, which appears to be a good fit to ITS, (DeBresson, 1991) for the conditions that induce economic agents to enter into network relationships, and for how networks serve search and evaluation functions, and (Lynn, 1996) for a broad framework for network analysis that fits the complexity and breadth of ITS, for discussions of various types of trade and industry associations, and for a comparative analysis of the effectiveness of various associations.

To conclude and summarize this section, I cite a study in which DeBlasio reviewed the results of Field Operational Tests to identify the institutional and legal impediments to ITS implementation. (DeBlasio, 1996) He found from his respondents that the need for *learning* was an underlying and universal theme:

They said, “Educate yourself, educate your partners, educate your management, educate your coworkers and subordinates, educate other possible players, educate government officials, and educate the general public.”

## 4. Locality, smallness, and privateness

In earlier sections I have shown a number of ways by which local, small and private projects contribute to technology innovation in ITS. In this section I further highlight the case for these qualities.

### 4.1 Costs and Benefits of Interagency Coordination

Wilson (1989) states a basic law of public agencies: By increasing their autonomy they lower their cost of organizational maintenance. They accomplish this by:

- minimizing external stakeholders and rivals
- maximizing the cohesive sense of mission
- reducing constraints
- simplifying tasks
- maximizing control of resources

Hence maintenance and enhancement of autonomy is an overriding goal of public agencies. They do not seek autonomy because their managers have primitive territorial urges; they do so because *that is what they do*. Therefore interagency coordination should never be sought lightly, and, when it is, only if an overriding purpose is to be achieved.

While it is axiomatic in the ITS world that interagency cooperation is difficult to achieve, it is not always appreciated that agency autonomy is an imperative of bureaucracy, not a quirky aberration associated with individual agencies or unenlightened leaders.

### 4.2 Costs and Benefits of ITS Integration and Interoperability

...new things piece not so well: but though they help by their utility, yet they trouble by their incomformity.

Francis Bacon, *Essays, Of Innovation*

They tell me that Maine can now communicate with Texas. But does Maine have anything to say to Texas?

Henry David Thoreau, 1840's, having being told of the great powers of the telegraph

As with any development decision, the benefits of integration must be shown to outweigh associated costs. The ITS literature is filled with assertions of the great benefits of coordination among regions, technologies, and services; a classic statement of this view was made by then-Secretary of USDOT Federico Pena, when he said, in reference to the benefits of integrating traffic and transit

management “into a single comprehensive system” that “the sum of these independent technologies is vastly greater than the parts.” (Pena, 1995). An ITS America brochure stated that “benefits multiply at increasing rates as more ITS services are added.” (ITS America, 1996) An employee of a systems integrator claims that “systems that communicate intelligently from the roadside and local level to state and national operations will extract the maximum results from the limited funding and resources available.” (Yoshida, 1996) There is little evidence to support such claims. In fact, the benefits of coordination and interoperability are among the least understood of all the impacts of ITS. There is no doubt that these benefits exist (often falling into categories of “convenience” and “mobility” enhancements), but there is an open issue on their magnitude, and it is doubtful that the spectacular gains claimed simply from coordination and integration can ever be realized.

In keeping with these optimistic views on the benefits of integration, the national ITS program continues to promote it as a centerpiece of its effort. One of its “few good” measures of ITS progress and achievement is a “count” of ITS integration, comparing number of components connected against some “possible” number. The score as of early 1998 is 22% (Inside ITS, 1998), although it isn’t at all clear what this number means in terms of benefits or cost-effective progress towards increased benefits.

Another (and some might say, more sinister) perspective on the value of integrated systems can be found reflected in (Slevin, 1997), where the author, in calling for good ITS “storytellers,” welcomes integration as a “*deus ex machina*” to provide a compelling justification of the federal ITS program. Again, the *actual* benefits of integration remain unexamined.

If the benefits of integration are murky, its *costs* are well understood and rarely small. The organizational, technical and economic costs of integrating any large and complex system can be very large indeed. The recent merger of Southern Pacific and Union Pacific train systems has “spread chaos throughout the nation’s rail system” (Nolte, 1997) as a result of the extreme difficulty the new company has had in integrating the previously independent parts into a single new system. These difficulties exist because of both institutional and technical mismatches (amplified by the large numbers of such interfaces in large systems, and because of complex interdependencies), and they can take substantial time and resources to overcome. The learning networks described in the last section, in fact, are a fundamental mechanism for innovating and integrating complex technologies. However, these networks take time and resources to support and grow. The Union Pacific discovered that complex systems can’t be joined instantly.

Clearly, the larger and more complex a system is, the more pieces there are to integrate, and the more difficult that task is. Of course, that is a basic rationale for establishing standards, but standards also take time and resources to

develop, and can create other costs as well, through inhibiting a more desirable line of technology evolution. The trade-offs tend to be complex here, with much uncertainty. Good overviews of the subject, with numerous case studies of relevance to ITS, within a comprehensive economics perspective, may be found in (David, 1987, 1988).

Gifford *et al* (1996) perform a comprehensive analysis of how many of these issues (and more) played out in a regional electronic toll-collection system, E-Z Pass. Among the important questions addressed are the benefits and costs of interoperability. The processes required for achieving institutional agreements on interoperability, for establishing system requirements, and for obtaining “cutting edge” technology are all described in informative detail. One unanticipated result of the interoperability goal is that the most technically demanding agency requirements tended to define the ultimate system. (See also a similar phenomenon in the California ETTC experience as reported in (Samuel, 1997).) Thus, some users (whose requirements are less stringent) will be cross-subsidizing other users (whose requirements are more demanding). Gifford makes the following interesting observation:

If the level of cooperation required for success is high, and if cooperation generally requires accommodation of the most demanding participant's requirements, then there is a general case against interoperability, *ceteris paribus*. The reasoning is that the more parties there are to an agreement, the more difficult it is to establish the necessary level of trust for an interoperability agreement and the greater the likelihood is of broadening the range of requirements between the most and least demanding of participants.

Service and agency integration is not always the best policy: the costs and benefits of interoperability should be carefully weighed in each case. Often, the existence of distinct local agencies reflects real differences in goals, traffic, customer needs, and the political/financial environment. Hansen's study (1994) of innovation in transit agencies highlights dramatically the uniqueness of each agency.

Although interconnection is abstractly desirable, its concrete payoff depends on demand and value: national compatibility for electronic toll collection adds little to direct user benefits as compared to state or regional compatibility. It can also happen that proprietary *in*compatibility has value, e.g. with Mobil and Shell Oil Corporations' systems for electronic gas payments. (Inside ITS, 1997)

Over the long term, the costs of interoperability will in general decline. Judicious and timely development of appropriate standards will facilitate this process. While I have emphasized the costs of interagency coordination, it is also true that appropriate architectures and decision-making protocols can reduce some of these costs or completely remove them. See, e.g. Hall (1997a), where he also points out the clear value of state-wide architecture and standards for two major classes of transportation management functions: 1. procurement,

maintenance and operation of field devices, and 2. communication and shared TMC-to-TMC interfaces, for “smart corridor” and signal/meter coordination, as well as for incident response and management.

#### 4.3 Incremental Design and Small, Local Projects

Small, local projects facilitate *incremental* design and implementation processes. As I asserted in earlier sections, much of technology innovation is based on small, incremental steps involving active doing and using, supported by learning networks. The literature of engineering design is filled with cautionary stories about the risks of large projects involving single leaps in technology. The Advanced Automation System is one such instance.

We tried to do advanced technology, computer replacements, new procedures, new soft-ware, and new decision support services all at once. We didn't realize the full scope of human factors. We put too much risk in the program in terms of pushing technology too fast. We underestimated the magnitude of the change. (Perry, 1997)

The FAA has now adopted a policy of evolutionary change for its air traffic control system.

In a different kind of complex design problem, Boeing implemented a new computer-aided design, manufacture and simulation system with the development of the 777. (Norris, 1995) While this reflects a remarkable innovation (the completely automated design of a complex aircraft), it is notable that: 1. the computer-aided design system had been previously developed and tested on parts of other aircraft, and 2. while the 777 has many innovations, it is not a radical leap forward from the 767. In addition, their automated system was designed to *enhance* communication among the design and manufacturing elements, thus improving the active learning features of their design process. Hence, Boeing took advantage of incremental features in their innovation.

Hickman (1994) reviewed the early operating experience of the BART system to draw inferences for AHS development strategies. One of his conclusions was that the radial nature of BART design was valuable in permitting incremental deployment, alleviating pressure to bring the entire system on line (in the face of numerous early problems), and allowing some lines to learn from the operating experience of others.

The American political system also tends to discriminate against large changes where a significant public investment is involved:

...most changes are small and most innovations are incremental. Rarely do we entirely overhaul our basic ways of doing things. While everyone agrees, for example, that the health care system needs reform, note how difficult it is to erase the current system and replace it with another. It is

much easier to reach consensus on raising the gas tax by a few cents than on replacing the gas tax by congestion tolls.

One reason for this consistent pattern is that proposals for change must pass many political tests. While victory at one level may only ensure that the idea will live long enough to be tested at another level of government, failure at any one level can whisk the idea out of systematic consideration for good. Usually it's only the safer, marginal changes that are supported by so many interests that they pass muster in every test. Entirely new ways of doing business are rarely adopted because their opponents need defeat them only a few times.

New ideas must have tireless and sophisticated proponents who "work the system in favor of their concepts. Usually, those who do work the system to promote some innovation have a lot to gain from its adoption.

(Wachs, 1994)

In spite of continuing ritual endorsements of interoperability on a grand scale, there are increasing good examples of incremental implementation in small, local settings in ITS, suitable to the political environment described by Wachs. A recent review by Bland *et al* (1997) stressed low-cost approaches to ITS for rural applications. These solutions were small-scale and local. Although the character of these projects were in part determined by the limited funds available for rural applications, as compared to urban ones, they can also serve as more general models. They confirm that local agencies can and are taking the initiative in developing projects that fit their particular needs.

Recent advice regarding incremental system design and implementation can be found in (Tarnoff, 1997) ("consider starting small and building incrementally") and (Dalgleish, 1996) ("All innovative solutions are implemented on a small scale to begin with.")

As pointed out in (Dahlgren et al, 1996), Orange County ITS deployments are an incremental extension or adaptation of the Los Angeles ATSAC system, with a further local seed planted in Anaheim, and effecting installations in Santa Ana, Irvine, and the expanded Caltrans District 12 TMC. Similarly, the Smart Corridor system in Los Angeles (coordinated traffic management along the Santa Monica freeway and neighboring arterials) is an extension of both the Los Angeles ATSAC and Caltrans District 7 TMCs. In the same way, successful local private projects at SR 91 and, in the non-transportation example cited earlier, the Ocean State Power Plant, also provide "seeds" for replication elsewhere.

#### 4.4 Utilizing Market Mechanisms

Throughout this study I have emphasized the value of privatizing ITS functions. In sum, the potential advantages are improved



- expertise
- efficiency
- flexibility
- cost
- incentives and ability to innovate

Yermack (1996) summarized the case for ITS privatization through contracting, and emphasized the advantage of obtaining expertise otherwise unavailable to a public agency.

To complete the picture, however, I cite some of the potential disadvantages of privatization. They include:

- transaction costs of accountability, due to increased efforts in
  - planning
  - negotiation
  - direction
  - evaluation
- equity questions and conflicts

For these reasons, privatization is most useful when outputs are most observable and easily measured, especially where customers can “vote with their feet” (more accurately with their cars). Yermack (1996) identifies performance measurement as a major challenge in privatization contracts. This problem is exemplified in the TravInfo problems with their major software contractor (Hall, 1998), partly a result of the difficulty of measuring the true output of this task.

Strong leadership and good management is inevitably found in successful public/private projects. However, there are also many other factors involved, and I have not aimed for completeness in touching on this large subject. A comprehensive survey of important issues in ITS privatization can be found in (Peterson, 1995).

## 5. Conclusions and Recommendations

### 5.1 Conclusions

ITS, like other new system technologies, requires the acquisition of knowledge by many diverse, interacting agents through active processes of learning by doing and by using. Small, local projects are valuable parts of this technology evolution process, especially for innovations that can proceed in incremental steps. They provide opportunities for learning about operations, maintenance, system integration, and customers, and help the growth of formal and informal supporting networks of experts and institutions. An important function of public policy should be the development and maintenance of these support and learning networks, in an environment of locally diverse and active operating experiences.

Interconnection and compatibility are inevitably and deeply important for ITS deployment, *at some scale, in some time frame, and for some technologies and services*. Integration should not be an end in itself, and should not be promoted to the degree that the many virtues of small, local projects are lost. Public decision makers should think as much about how to value, honor, and exploit local differences, as how to submerge them within large interconnected systems. Best of all, diversity of practice and experience can be respected within an evolving framework that supports cost-effective coordination.

Planning should be done in close contact with developers, testers, and operators. Funding agencies should require that planning agencies establish technical review panels composed of objective, technically knowledgeable people, to review and comment on regional transportation plans that involve new technology. Similarly, at state and federal levels, local operators and experienced developers and consultants should be involved in significant review and advisory capacities. Funds should be provided to facilitate the participation of such experts. Test beds should be incorporated into regional operations and should include a broad range of partners, each executing tasks that match their core competencies, and contributing to the execution of projects that are locally important. Wherever relevant, private industry skills should be tapped. Operations experts should have a substantial role in setting the research and development agenda. Regional and local forums should be established for sharing planning questions (from cities, regions, and states), operational experience and needs (from public operating agencies), and research and test results (from University and industry developers). The objective of such forums should not be promotion of ITS, nor should it be similarly motivated “education” of operators; rather it should be on exchange of core factual experience on operating conditions and needs, and performance experience with new technologies. Even beyond sharing this kind of

information, such forums, if they include people with real knowledge and experience, can help establish trusting relationships for future interactions and information exchange, based on need rather than promotional visions.

Regional networks for learning should be particularly nurtured. Models are the ITS Technology Transfer Program at UC Berkeley and the CalSkills Alliance for Transportation Technology Training in California. However, in the absence of active local and regional projects, the effectiveness of (and need for) such networks is diminished.

More comprehensive and credible system performance measurements should be made on a routine basis, and will support all other activities and decisions. Such data should be collected based on standard, clear, logical measures and protocols, and summarized for ready comparisons over time within and among systems. At best, Intelligent Transportation Systems without such information forego what is arguably the special strength of ITS; at worst, they are doomed to drift without consciousness of their value or direction. The availability of such information will make planning more meaningful and honest, and make real benchmarking possible. With benchmarks founded on useful measures (including user valuations), and data routinely obtained based on these measures, progress toward stated planning goals can be tracked, thereby reducing the role of after-the-fact spin doctoring of project results.

ITS America should continue to intensify its efforts to strengthen its state chapters. A particular objective should be to actively couple federal, state, and regional ITS programs and plans to working experts and operators.

## 5.2 Recommendations for Further Study

To write books upon minute particulars were to render experience almost useless.

It is the ways of scholars to show all they know and oppose further information.

Francis Bacon, *Advance of Learning*

For reasons more reflective of my weaknesses than my strengths, I seem to have avoided both of these pitfalls. First, it is obvious that this work is not filled with “minute particulars.” Second, while I may have shown all I know, what I have shown is more sketch than solid study. These shortfalls should therefore not “oppose further information,” but rather encourage it.

My arguments will remain largely speculative without future studies to either confirm or refute them, and to go beyond the kind of anecdotal evidence I have offered. Following is a list of research topics that appear to me to be both

intellectually interesting and potentially useful in understanding how to facilitate ITS deployment.

1. Develop a multi-dimensional taxonomy of each ITS service, technology, and device, that classifies them on the basis of the various standard descriptors used in the literature of technology innovation. Examples of these are: Kash and Rycroft's (1997) "complexity" (perhaps modifying their definition to better fit ITS), and Utterback's (1994) "assembled/non-assembled," "market substitute/enlarger," and "competence-enhancing/destroying." Another dimension is "continuous vs. discontinuous" innovation, and closely related, short- vs. long-term. Further dimensions are connected with public/private (either or both), the form and level of the relevant public organization(s) (local, regional, state, and national), the size and relevance of existing technology bases, and the role of installed technologies. On the basis of these classifications, then, draw distinctions among the various ITS services, technologies, and devices.

2. Pick particular ITS service(s) or technologies and study them in depth as innovation cases, using tools from the current literature, while recognizing the need to accommodate ITS idiosyncrasies. An interesting set of examples would include both early "successes" and "failures."

3. Study the role of various professional and industry organizations in facilitating the development of ITS. Examine the record of ITS America, and its diverse roles as federal advisory organization, professional society, and industry promotional organization. Compare this ITS history to other technologies.

4. What "learning networks" have developed in ITS? Consider both formal and informal networks, and compare them with published histories from other industries. What are their structures, roles and effectiveness? Examine the specific roles of professional and industry organizations, universities, public agencies, and professionals, including operators, designers, manufacturers, and consultants. Review the roles of various standing ITS committees, including the technical committees of ITSA, TRB, ITE, and SAE, and the standard development committees of various professional organizations. Identify and track the (evolving) relationships among the different participating organizations. Track the movement of leaders and key professionals among various organizations. Are there organizations or individuals who act as "strategic centers" to manage a web of partners (Lorenzoni and Baden-Fuller, 1995)? What new organizations, institutions, and agencies have developed? Examine the coevolution of ITS institutions and technology, recognizing the challenging analysis and modeling problem here (Nelson, 1994). Consider the "innovation community" framework offered by Lynn et al (1996) as a basis for such studies.

5. One of the major differences between ITS and many of the case studies in the literature of technology innovation is the major role of a very complex set of influential public bureaucracies, in turn connected in various ways to citizen and special-interest constituencies. Explore these features as a determining difference with other technologies, and look for similarities in other fields, e.g. civil aviation. A study could consider a single type of agency (reviewing various specific agency instances as examples) as a "horizontal" cut, or all the agency types involved in deployment in a "vertical" slice. Because of the ITS leadership of the federal government, a case study of their role (in the context of other similar government programs in other industries) could be of value.

How is support for ITS innovation affected by the evolution toward greater power for MPO's? How is innovation affected by MPO strength, structure and responsibilities (for coordination, plan generation and approval, fund raising and allocation, and operation); regional needs, politics and economics; and relationships with state and local agencies?

How does agency mission and authority affect their selection of areas of innovation? E.g. what determines selection of project size and type, the prioritization of integration, etc.?

6. How do mission, organizational structure, leadership, technology, and other factors combine to affect ITS innovation in public transportation agencies? A comparative study of state, county, and city DOT's would be very useful. What innovation strategies have been particularly successful or unsuccessful? Have organizational innovations been successfully achieved, including recruitment of new key personnel? What are the roles of "technology champions", "young officer corps"? To what extent is successful innovation dependent on strong leadership and clever management?

7. I have largely ignored the role of the network nature of ITS, in order to focus on a complementary set of phenomena. Bring the complex network nature of ITS into the picture, and explore these implications. The Gifford et al case study of electronic toll collection (1996) is a good example of what can be learned in this context. Use case studies to determine factors that make early integration and standards development more or less feasible and desirable.

8. Examine particular ITS commercial products and services to determine how market structure, technology, and public policy combine to affect the innovation process. A starting point for such a study would be to survey and describe the companies presently engaged in various ITS product categories, including their roles, histories, and interactions. A quick count of such companies can be made from the list of exhibitors at the ITS America 1997 Annual Meeting. A cursory review yields the following numbers of private firms in various ITS markets: system integration (23), surveillance and sensors (22), miscellaneous products (including navigation system components and traffic controls) (22),

communications (19), signs (7), and electronic toll collection (5) (ITS America, 1997). (I assigned each firm in just one, “primary” category even if they were involved in more than one market.)

Surveillance technology might be a good choice because it is unique to ITS, and underlies many important ITS functions. It also appear to be somewhere in the “fluid phase” of the S-curve, with a fairly large number of small firms. Thus researchers have an opportunity to work with a fairly large number of firms to begin to collect data and perform interviews and surveys, at a time near the beginning of the innovation process.

In-vehicle technology could be the basis for another kind of study, involving the automobile manufacturers, and including the navigation systems (that have not proven popular in the US) and the safety/security systems (that have found more success). The emergence of several comprehensive, in-vehicle PC-oriented systems from Microsoft and Intel is an important event to include in such a study. Such systems also offer the possibility of studying the “autonomous” emergence of commercial standards.

Systems integrators could be another interesting subject for study, given the central role they play in the definition, promotion, and execution of ITS systems. Furthermore, there is a complex history here of firms with quite different histories (aeorspace and defense; traditional transportation consultants). There are also important issues involving proprietary vs. open systems; these issues are strong determinants of costs and involve basic corporate strategies and questions of public policy.

9. Most of the examples of ITS technology in this study have been near-term ones. Perform a similar analysis for longer-term technologies. A case study could consider various categories of advanced vehicle control systems or highway automation. A specific case study could look at the history of the Automated Highway and Intelligent Vehicle Initiative programs.

10. Perform case studies of strategic planning in ITS at regional, state, and national level, and evaluate their impact and effectiveness. Compare them with planning in other industries, e.g. with the National Technology Roadmap for Semiconductors (Moore, 1996). Identify barriers to effective planning in ITS, e.g. based on the roles of public agencies, their separation of planning and operational responsibilities, and the lack of clearly defined, standard measures of performance in routine use.

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