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Randolph W. Hall

Partners for Advanced Transit and Highways

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Partners for Advanced Transit and Highways
Institute of Transportation Studies
University of California, Berkeley

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INTRODUCTION

Advances in information, computation, and communication technologies in the 1970s, 1980s and 1990s have stimulated remarkable changes in business practices throughout the world. It is now possible to accurately track, automate, and control production from the moment raw materials are extracted from the ground until finished products are delivered to customers. Office environments have also radically changed with the introduction of word processing, computer-aided-design, and an array of databases. And service industries have also been altered through products ranging from medical diagnostic equipment to systems designed to monitor delays in fast-food restaurants.

Against this backdrop, we have seen relatively modest changes in road transportation systems. In many fundamental respects, the automobile is little different from the 1950s and 1960s. The principal driver tasks of steering, propulsion, braking, signaling and gear changing have experienced few advances in automation. Furthermore, drivers still communicate with each other by the primitive means of flashing lights and sounding horns. And coordination is limited to illuminated signals, simple roadside signs and the rules of the road.

In the late 1980s a movement began in the United States, Japan and Europe to develop and apply electronic and communication technologies to road transportation system, with the goal of solving congestion, safety and pollution problems. This movement aims to upgrade the transportation system to the level of automation and control now seen in "world-class" firms in other industries.

Now called "Intelligent Vehicle Highway Systems" (IVHS), the movement has attracted investments from a vast number of organizations, including the federal government, automotive companies, aerospace companies, and a spectrum of high-tech companies. Today, IVHS is reaching a state of maturity where commercial products are becoming available, and research is continuing across a vast spectrum of technologies.
Within this paper, the market for IVHS products is assessed from a research perspective. Ultimately, this market will depend on the benefits that accrue to individuals, businesses and government. With the huge number of companies already developing products, only a small percentage are destined to prosper. Those that do succeed will possess a thorough understanding of the costs and benefits associated with launching products into the competitive IVHS marketplace. Research can provide this understanding.

CALIFORNIA PATH

California PATH is a consortium of universities, government and companies that conducts research in IVHS. Administered through the Institute of Transportation Studies at the University of California at Berkeley, PATH receives major funding from the California Department of Transportation’s (Caltrans) New Technology Division. In addition to Berkeley, PATH university members include U.C. Davis, U.C. Irvine, U.S.C., and Cal Poly San Luis Obispo. PATH projects have also been funded at Stanford, U.C. Riverside, Rockwell, Qualimatrix and other organizations.

PATH concentrates its research in three areas: Advanced Transportation Management and Information Systems (ATMIS, headed by Randolph Hall), Advanced Vehicle Control Systems (AVCS, headed by Stephen Shladover) and Systems Integration and Institutional Issues (also headed by Randolph Hall).

ATMIS. The thrust of this program is on near-term technologies, implementable within a five-year time frame. This includes traveler information, route guidance, traffic surveillance, traffic signal control, and communication systems. For example, PATH is currently funding research on tracking based video-image-processing, and design of digital-packet-radio systems for vehicle-vehicle and vehicle-road communication.

AVCS. Within this program, the emphasis is on the eventual automation of driver functions, including steering, propulsion and braking. This may lead to fully automated-highway-systems (AHS) that operate with
much higher capacity than today, through precisely controlled vehicle separations. In addition, many AVCS technologies can be applied for collision avoidance and collision warning, with the goal of improved safety. PATH is currently testing sensing and control technologies on full-sized vehicles, at its lateral-control track in Richmond, and on the I-15 freeway in San Diego.

**Systems and Institutions.** The focus of this program is on the integration of technologies and on overcoming barriers to their implementation. Examples of this work include development of time-phased deployment plans for IVHS (spanning ATMIS and AVCS) and system architectures, as well as policy analysis.

Beyond its breadth and size, PATH’s most unique accomplishment has been its success in building partnerships between organizations and across economic sectors. Collaborations with the private sector and between universities receive high weight. In addition, PATH has established coordinating councils and focus groups to share research results and coordinate work.

**Benefits Evaluations**

PATH has conducted and funded studies to evaluate user and collective benefits derived from traveler information, collision avoidance, adaptive signal control, and automated highway systems. These studies have included computer simulations, driver simulations with human subjects, fault tree analyses and user surveys. In addition, PATH funded a study performed by Rockwell to develop a broad survey/assessment of "IVHS Payoffs," which included a detailed survey of the IVHS literature. PATH is also in the process of negotiating a contract with the Federal Highway Administration to perform a cost/benefit analysis on automated highways. As a whole, PATH likely has more experience in IVHS benefit analysis than any other organization in the country.

**Individual and Collective Benefits**

In the transportation research community, "user optimality" and "system optimality" are familiar concepts. The first term describes how a
transportation system performs if each user seeks to optimize his own benefits. The second describes performance when users optimize benefits for the system as a whole. The difference between the two is the difference between collective and individual benefits. If an individual changes his travel route or departure time, for instance, he might enjoy the benefit of a shorter travel time. In addition, other users might enjoy the benefit of having one fewer driver on the road — a collective benefit.

Understanding individual and collective benefits is crucial to understanding the IVHS customer, whether it be the individual, industry or government. **Federal and state governmental** objectives center on collective benefits, namely reduced highway fatalities, increased productivity due to reduced highway delays, and reduced pollution through reduced congestion and improved vehicle performance. To a great degree, the federal government (and California as well) is also motivated by the need to transition defense industries to civilian activities. And, unfortunately, governmental objectives are sometimes motivated by a desire for high-visibility projects, which give the appearance of progress, whether or not progress is actually achieved.

At the **local level**, governmental objectives tend to be less expansive. Controlling traffic signals to minimize delay or to process traffic leaving special events is most prominent. Regional and national problems, such as air pollution and defense conversion, are not high on the agenda. For that matter, neither is IVHS.

It is also useful to think of **regulators** as a distinct governmental market. Regulatory agencies are both potential purchasers of IVHS products (e.g., vehicle identification tags and readers, weigh-in-motion equipment, emissions monitoring, etc.), and have the power to direct purchases by individuals and businesses (e.g., vehicle mounted collision avoidance devices). The motivations are collective, with heavy emphasis on safety, followed by pollution control and tax collection.

**Individual** motivations are, by their nature, more personal. Saving **one’s own** time is important, but so are the intangibles, such as comfort, performance and enjoyment. People tend to put less weight on broader concerns, such as air pollution and defense conversion, in their individual purchases.
Finally, **business** purchases, like individual purchases, are usually less motivated by collective benefits than by direct benefits to the firm. Travel time savings, improved service and, above all, reduced cost and increased revenue are major considerations for fleet operators. Vehicle manufacturers and system integrators buy largely on the basis of what they believe the ultimate consumer is willing to purchase.

**Segmenting the IVHS Market**

Much of the excitement surrounding IVHS has come from its "gee-whiz" value. Modern traffic operations center and night-vision surveillance systems have much more cachet than a few miles of pavement or a new highway superstructure. What's more, the clean environment of a TOC seems much more environmentally benign than the freeway, with its throngs of traffic, and concomitant noise and pollution. While these "gee-whiz benefits" may be sufficient motivation for initial IVHS investments, in the long run only tangible returns can sustain the industry.

Based on what we know so far, investments in advanced signal control systems are cost-effective from the standpoint of reduced congestion. Ramp metering systems can also be cost-effective, but less so than arterial control systems. Traveler information systems are largely untested, so any measure of benefit must come from simulation-type studies. Here, it seems that benefits to the users can be significant, but not so significant to justify current costs of $2,000 and up. Collective benefits are likely to be marginal, and certainly not sufficient to justify major public subsidies. Highway automation has the potential for major reductions in congestion, but there is some fear that this will be offset by increased trip-making and increased trip-length. Fleet management systems, including vehicle location tracking and guidance, also look cost-effective. Unfortunately, with the exception of long-term automation technologies, none of these IVHS technologies is likely to make a significant dent in congestion. Within the short-term, only automated toll collection coupled with congestion pricing looks viable in tackling this problem, but this may be a case where the solution is worse than the problem (at least from the public's perspective). For the most part, collision avoidance and warning devices are untested. It is unclear whether they can, in the short-term, produce any benefit.
With respect to benefits, technologies can be segmented as follows:

**Workhorses** — Proven technologies, primarily in the local government market, with favorable cost/benefit ratios, best represented by signal and ramp control systems. Over the next ten years, advanced inter-connected and adaptive systems will become increasingly common as existing mechanical systems are upgraded. In addition to reduced delay, benefits may include reduced maintenance and greater flexibility to adapt to changing traffic patterns.

**Up and Comers** — Devices and systems already introduced to the market, or soon to be introduced. Once scale-economies set in, cost/benefit ratios will likely support a large market, though the market has yet to be proven. Examples include in-vehicle guidance systems, video surveillance systems, and vehicle identification for toll collection. Here, the initial market will likely be with fleet operators and government, later with individuals.

**High Risk/High Payoff** — The unproved technologies currently being researched for 10-20 years down the road. The set of technologies surrounding automated-highway-systems typifies this group. With potential capacity increases of a factor of two or three, this is the only category (other than pricing) that could possibly make a substantial dent in the congestion problem. The problem is, we don't yet know if it will work and, if it does work, whether it will be accepted.

**Show-offs** — Technologies that make a strong presence, but offer no appreciable benefit now or in the future. All too often, the category is typified by the "good idea looking for a problem" or the "solution that is worse than the problem." While the show-offs likely constitute the majority of the ideas being studied today, they are quickly being weeded out, both through research and in the marketplace.
TECHNOLOGY PARTNERSHIPS

Beyond creating solid products, with solid benefits, the most difficult part of selling IVHS products is building the technology partnership. This entails forming alliances across organizations to deploy viable systems. An immediate example is the market for real-time information on travel conditions. A vast number of devices have already been developed to do just this. The problem is acquiring the information to support them.

While the devices are sold to individuals, the supporting information may only be available from government agencies who run surveillance systems. Or, even if the information is not currently available from the government, it may be too expensive for an individual company to develop and operate a surveillance system, solely to support its own devices. IVHS is not so old that companies haven't failed, principally because they could not afford to build and operate the infrastructure, or because the operating costs resulted in excessive monthly charges.

A solution to the problem is the technology partnership. The Bay Area's TravInfo is an excellent example. TravInfo, when implemented, will provide an open-access database on the latest traffic and transit conditions throughout the region. It may also, in the future, provide for data broadcasts. To draw an analogy, such a partnership would relieve the technology developers from having to both "sell the T.V. sets" and "run the T.V. stations." The developers can concentrate on what they do best, and government, at a reasonably modest cost, can spread the infrastructure costs across all users.

Further down the road, automated highways will demand even stronger partnerships. No longer will vehicles operate autonomously under human control. Instead, vehicles may come under complete computer control, with movements coordinated by infrastructure mounted controllers. In the eventual AHS market, a major concern will be achieving an effective confluence of infrastructure upgrades and vehicle upgrades. To operate on an AHS, vehicle purchasers will undoubtedly have to acquire special equipment, such as "drive by wire" control over steering, braking and propulsion, and special sensors and communication devices. But on the day an AHS opens, what will guarantee that anyone has such equipment?
The solution will have to come from a partnership based strategy, whereby users enjoy appreciable benefits prior to full infrastructure deployment. These benefits may not be the sought after goals of reduced delay and faster speeds. They may instead be comfort on long trips (through advanced forms of cruise control) or added safety (through collision avoidance). But no matter how the deployment strategy evolves, it can only be successful if automotive manufacturing strategies are coupled with infrastructure deployments, as well as regulations to ensure inter-operability.

**MOTIVATING THE PARTNERS**

No partnership can succeed unless there are clear benefits to all its members. Hence, technologies that demand governmental investment or even governmental attention must do more than benefit individual purchasers: there must also be a clear collective benefit as well. With budget squeezes on the local and state level, and to a lesser degree on the national level, this is not an easy sell. A city traffic engineer, given the choice between filling pot holes or supporting navigation devices wouldn't have to think long before choosing the former. Nevertheless, local and regional agencies, such as the City of Los Angeles and the Metropolitan Transportation Commission, and state agencies, such as Caltrans New Technologies, have been among IVHS' biggest advocates.

Success in partnership building is a matter of sticking to basics. Government, like the private sector, responds to its own type of "customers", and understanding these customers is a key to success.

**Solve a Problem** — The partnership must have a clear mission directed at a recognized problem, such as congestion, traffic accidents or pollution. Or, better yet, the partnership should increase efficiency or bring in revenue, allowing governmental dollars to go further. The mission should not be technology deployment.

**Build a Team** — The strength of the partnership is the strength of its members. Integrating their ideas will both improve the system and build a legion of advocates.

**Target the Right Level** — IVHS is regional and national in scope. No company can afford to build a separate partnership, and separate
solution, in each city of the country. The focus needs to be on the metropolitan region or larger.

**Keep Costs Low** — Government, especially local government, has limited money to spend on expensive projects, except, perhaps, in the area of signal control. When it comes to supporting devices sold to the public, government should not be counted on for any financial support. Nevertheless, government plays a vital role in the areas of standardization, data collection, right-of-way acquisition and team building. The governmental "customer" should not be viewed as a source of revenue but as the catalyst for deployment.

**Understand the Customer** — Government is not monolithic. Each agency has its own personality, often at odds with others. The local agency will be sensitized to impacts on communities. The state agency will be sensitized to the legislature, and projects that bring them recognition. Partnership building depends on providing clear benefits to each participant, even at the expense of the system as a whole.

**CONCLUSIONS**

IVHS presents the opportunity for raising the country's transportation system to the "world class" standards of private industry. But in the process, developers of IVHS technologies face enormous challenges. Perhaps unlike any other set of products on the market today, success in IVHS depends on a merger of talent and commitment across disciplines, across organizations and across sectors. In this complex environment, firms need to understand the goals and objectives of all participants. While "gee-whiz" technologies may have initial appeal to some buyers, no product is likely to go far without demonstrated benefits in excess of cost.

IVHS is destined to become a major market. But no company should view this as a ready substitute for the shrinking defense expenditures. The survivors will be the ones who understand the market needs at all levels — individuals, government and business — and develop products that respond to these needs. The failures will be the lazy companies that simply try push their existing products without regard to market needs.
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