PATH at 20 – History and Major Milestones

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Abstract— **The California PATH Program was founded in 1986, as the first research program in North America focused on the subject now known as Intelligent Transportation Systems (ITS). This paper reviews the history of the founding of PATH and of the national ITS program in the U.S., providing perspective on the changes that have occurred during the past twenty years.**

Index Terms— **automated highway systems, intelligent transportation systems, transportation history**

I. Introduction

In the world of institutions, especially academic institutions, twenty years is not a particularly "big" anniversary. However, for a research program focused on a specific field of rapidly changing technology, twenty years is a long time and an anniversary worthy of note. For those of us involved in starting the PATH Program, it is sobering to realize that we have been at it for such a long time and to notice that there has been almost a complete generational change of people active in the field. Since most of the people who were active in our field twenty years ago have retired by now and most of the people currently active were not involved twenty years ago, it is useful to explain the history behind the creation of PATH and of the entire field of ITS. This provides an opportunity to revisit the thinking of that time and to contemplate the changes that have occurred in the intervening twenty years.

The story begins with an explanation of the needs and challenges that motivated the start of ITS, and why it started in California (at least for North American activities). The "upstart" group that developed the technical and programmatic concepts for ITS had considerable work to do to gain the attention of the transportation establishment, and that process consumed several years before substantive support could be achieved. The key stages of that process are described to provide some history of the development of the national ITS program in the U.S. While the national program was being planned, PATH had already received substantial research funding support from the California Department of Transportation (Caltrans), which made it possible to initiate an ambitious portfolio of research projects on many aspects of ITS, giving PATH researchers several years of lead time ahead of their counterparts elsewhere in North America and making it possible to attract very talented research staff, students and post-docs.

It is not feasible to cover all the research accomplishments of twenty years and nearly a thousand labor years of work in one paper, but some of the highlights are described here, particularly where they are related to activities on the national and international scenes.

II. California Transportation Concerns in the mid 1980s

The major growth in California's famous network of freeways occurred during the 1950s to 1970s, but by the 1980s the network was essentially static. In the mid 1980s Caltrans realized that they needed to look ahead a couple of decades and determine how they were going to be able to meet the continually growing transportation needs of a state with a rapidly growing population and economy. Traffic congestion was becoming an increasingly acute public concern, as well as being recognized as an impediment to the future economic health of the state.

A planning study for the Los Angeles region considered a variety of alternatives for meeting the projected 20-year travel needs of the region. The only alternative considered in the study that could significantly ameliorate the growing congestion problems would have involved double-decking most of the major freeways, at a cost of $28 billion (in 1985 dollars). It was evident to all involved that this would be financially, politically, and environmentally infeasible, even before the seismic hazards of double-decked freeways were revealed by the 1989 Loma Prieta earthquake. This led to the important conclusion that "we can't build our way out of congestion". Very importantly, some of the people involved in the planning process recognized that there were possibilities for information technology to help with the problem, and decided to pursue that seriously.

Caltrans created an Office of New Technology in their Division of Transportation Planning to develop a research agenda to support their longer-term needs, and initiated a contract with the Institute of Transportation Studies of the University of California, Berkeley (UCB-ITS) for research support. They convened a small group of experts in Monterey in the spring of 1986 to assist in their planning, which led to the creation of a conference in Sacramento in October 1986.

The Sacramento conference, "Technology Options for Highway Transportation Operations"[1], is generally

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considered to be the landmark event in stimulating interest in what we now know as ITS in North America. Most of the 100 attendees (almost entirely from public agencies and universities, but not private industry) were from California, but there were also representatives from eight other states and the District of Columbia, as well as from Canada, Germany, and Sweden. A series of presentations and workshop discussions identified a wide range of ITS opportunities, including automated highways, as well as others related to clean propulsion technologies. Much of the Caltrans leadership participated in the meeting, and the conference proceedings contain several impressively visionary statements from people in senior Caltrans management positions. It is vital to recognize that major new initiatives require visionary champions in high places, and in this case there was a rare combination of such people in positions where they could make a difference.

III. Founding the California PATH Program

Developing and evaluating the effectiveness of new information technologies for transportation required a combination of technological expertise that was not available within the traditional civil engineering and planning capabilities of Caltrans' own staff. Caltrans recognized that the multi-disciplinary capabilities of the University of California could be accessed through the Institute of Transportation Studies (ITS), which had worked closely with Caltrans since its founding in 1948.

At the same time that Caltrans' interest in using information technology to improve transportation operations was developing, there was parallel work in California developing a method of inductively transferring electric power to a moving road vehicle so that its batteries could be recharged "on the fly". This project, focused on application to an electric bus for downtown Santa Barbara, was led by Systems Control Technology, Inc. (SCT), where I was the project manager, and an independent consultant, Howard Ross. This roadway-powered electric vehicle (RPEV) project had federal earmarked funding but needed an institutional "home" after the retirement of the general manager of the Santa Barbara Metropolitan Transit District led to the loss of its local champion. Howard Ross and I recognized the potential synergy between this project and the developing Caltrans interest in highway automation, in which we had both long been interested. We proposed combining the RPEV project with the new highway automation work under the auspices of the Institute of Transportation Studies to the Directors of both ITS branches, Prof. Adib Kanafani at Berkeley and Prof. Wilfred Recker at Irvine. Prof. Kanafani was intrigued by the opportunity and knew that he wanted to have Robert Parsons lead the project.

Robert Parsons had a long and distinguished career in managing advanced technologies for transportation, and had recently been working with UCB-ITS on a railroad systems research program. Earlier in his career, he had served as the Deputy Director of Supersonic Transport Development at the FAA, Associate Administrator for R&D at the Federal Railroad Administration, and manager of the Las Vegas-Southern California Phase II Super Train Feasibility Study. His experience with these diverse projects gave him an excellent understanding of the process of developing advanced technology systems and of trying to implement them via complicated public-private sector interactions.

Bob Parsons accepted the assignment as the first Director of the PATH Program and set it on a very solid foundation for future growth and health during its first four years, until his retirement in 1990. He chose the original name for the program (Program on Advanced Technology for the Highway), and when the program scope was broadened to be more inclusively multi-modal in 1992 he also chose the replacement name (Partners for Advanced Transit and Highways), preserving the PATH acronym. Parsons was an inspiring leader for PATH, with a rare ability to define a large-scale vision, while also understanding the practical steps that need to be taken to advance it to reality. He was a warm and caring colleague and supervisor, giving generously of himself to others. All who worked with him remember him as a man of great integrity who expressed his opinions candidly and without artifice or pretense. Bob Parsons maintained the highest standards of honesty and integrity, inspiring others to follow his example. Unfortunately, he did not live to see PATH reach its twentieth anniversary, having died in October 2005, but we are dedicating our twentieth anniversary commemorations to his memory.

Fig. 1 Robert E. Parsons (1931- 2005) PATH Founding Director, 1986-1990

IV. Outreach to Create a National Program

The initial impetus for using information technology to improve road transportation operations came from California, but the program founders at Caltrans and the University of California knew from the start that this was not something that California could do on its own. They knew that it would be necessary to create a national program in order to ensure nationwide interoperability of vehicles and to provide a large enough market for the new products and services that would be needed. Consequently, as soon as the program was created they devoted extensive efforts to missionary work in Washington DC and in other states and universities that had strong transportation research institutes and analogously strong relationships between their state departments of transportation and research universities.

In Washington DC, they found receptive ears in the Federal Highway Administration research staff, especially with Lyle Saxton, who had supported much previous research on automated highway systems at the Ohio State University from 1965-1980 and with Frank Mammano and Burton Stephens, who had worked on the Electronic Route Guidance System (ERGS) during the 1960s. The support at the staff level did not extend to the political level at DOT, where the marching orders throughout most of the 1980s from the Reagan Administration were to cut transportation R&D to the bone and not take any new initiatives that would incur financial commitments. In this atmosphere, it took considerable courage for the staff civil servants to participate in, and before long to lead, national meetings that would formulate the plans for the largest new ground transportation R&D initiative in decades.

The California missionaries (primarily Bob Parsons and Adib Kanafani from PATH and John Vostrez from Caltrans) also found receptive ears in Texas, particularly at the Texas Transportation Institute (TTI), in Michigan (University of Michigan Transportation Research Institute [UMTRI] and MDOT), in Minnesota, at MIT and at General Motors. With this relatively small core group of interested organizations, they began a series of workshops to discuss how a national program could be formulated, but did not yet have a concise way of describing what the program was about. The first such meeting, involving 25 participants, was held at the FHWA Turner-Fairbank Highway Research Center in McLean, VA in November 1987, on an agenda called "Advanced Vehicle Control Technology 'Focus' Meeting". It's particularly interesting to note that the focus was on vehicle control from the very start of activities.

Subsequent meetings were held at relatively short intervals, indicating the degree of enthusiasm and commitment among the volunteer participants, who did not generally have project funding to pay for their time or travel expenses:

- March 1988 – Berkeley, CA as "Multi-State Consortium for RD&D on Advanced Technologies for the Highway"
- June 1988 – Washington DC as "Advanced Technologies for the Highways Ad Hoc Steering Group"
- October 1988 – Ann Arbor and Chelsea, MI, including vehicle demonstrations
- February 1989 – San Antonio, TX, workshop with 57 participants, leading to published proceedings (2)
- April 1989 – Cambridge, MA
- July 1989 – Berkeley, CA, including vehicle demonstrations
- August 1989 – Washington, DC
- November 1989 – Washington DC, Ann Arbor, MI and Berkeley, CA (visit from PROMETHEUS secretary)
- March 1990 – Dallas, TX, workshop with 200 participants, leading to second-generation published proceedings (3).

The June 1988 meeting was held immediately before a TRB national workshop on the "Transportation 2020" program to define the next generation of transportation issues. Transportation 2020 (4) was a product of the leading transportation interest groups in Washington DC, the American Association of State Highway and Transportation Officials (AASHTO) and the Highway Users Federation for Safety and Mobility (HUFSAM), representing the traditional approach to transportation issues. It was important for the advanced technology group to present their case for an advanced technology element in the future national transportation plans, and they decided that they needed to have a name for their virtual organization before they could be taken seriously. Out of this necessity was born the name "Mobility 2000", which the group adopted in June 1988, and continued to use until it became the core of a new real organization in early 2001 (the Intelligent Vehicle-Highway Society of America, or IVHS America).

The vehicle demonstrations at the October 1988 and July 1989 events provided good opportunities for outreach to decision makers in both the public and private sectors, as well as representing attractive media events. These became some of the earliest opportunities for television coverage of the possibilities that new technology could bring to transportation, and included coverage of new products under development by start-up companies as well as established industry leaders. The Mobility 2000 workshops organized by Sadler Bridges and William Harris of TTI in February 1989 and March 1990 produced the first tangible documentation of concepts and program plans for the development of a national program. During this time, it also became evident that the entire technical field needed a name, and Kan Chen and Robert Ervin of UMTRI came up with the name that was eventually accepted – intelligent vehicle-highway systems (IVHS).

The efforts of Mobility 2000 began to bear fruit, attracting the attention and eventual support of the leaders of AASHTO and HUFSAM. They agreed to co-sponsor, with General Motors, a National Leadership Conference on IVHS in Orlando, FL in May 2000, and that meeting led to general agreement on the need to establish a permanent national organization that would be chartered as a utilized federal advisory committee to the

U.S. DOT. That permanent organization, IVHS America, was soon founded, with AASHTO and HUFSAM as its founding members and the Mobility 2000 activists becoming the leaders of its various technical committees. The U.S. DOT investment in the new field of IVHS was still negligible because there had not been any funding authorized by Congress under its existing legislation. This changed in December 1991, when Congress passed the Intermodal Surface Transportation Efficiency Act (ISTEA), which included a section specifically devoted to IVHS, with its own dedicated funding stream (significantly larger than expected by any of its proponents because of technicalities in the way the legislation was drafted).

More detailed information about the formative years of IVHS in the United States can be found in (5) and (6).

V. Parallel Activities in Europe and Japan

While the ideas behind ITS were germinating in California, analogous thinking was happening in Europe and Japan and similar programs were being established. Information exchange was quite limited for a while because the people involved did not generally know their counterparts on the other continents and because the programs had some strong elements of industrial competitiveness as well. The communication barriers were gradually broken down, in large part based on a few cases in which individual researchers knew people who were active on the other continents based on their prior work in other fields (magnetic levitation, high speed rail, personal rapid transit and automated guideway transit, vehicle dynamics and control).

The activities in Japan were initially difficult to understand because they were divided across four competing government ministries and many automotive industry competitors. Some of the relevant projects had begun in the 1960s and 1970s (Comprehensive Automobile Communication System – CACS), analogous to work in the U.S., leading to projects including the Road-Automobile Communication System (RACS) and Advanced Mobile Traffic Information and Communication System (AMTICS) at about the time that IVHS was starting in the U.S.

In Europe, Daimler-Benz Research stimulated the development of an ambitious industry-led program called PROMETHEUS (PROgraM for European Traffic with Highest Efficiency and Unprecedented Safety), developing a wide range of systems for traveler information, vehicle control and safety, while the public sector traffic management issues were being addressed in a European-Commission led project called DRIVE (Dedicated Road Infrastructure for Vehicle safety in Europe). The November 1989 visit to the U.S. of Hans-Peter Glathe, the Secretary of the PROMETHEUS program, was an important milestone in recognizing the parallels between our interests and programs. Each recognized that we could use the competitiveness threat of the other to stimulate political support for our work, but we also recognized that we had essentially the same goals. Indeed, after I briefed Mr. Glathe on the PATH Program goals during his visit to Berkeley, he asked to borrow one of my slides to use in his presentation of the PROMETHEUS program goals.

VI. Initial PATH Research Topics

The first two years of work at PATH were largely devoted to conceptualization, program planning, and missionary work throughout the U.S. By 1988, additional state resources were available to support the initiation of substantial research work. Since PATH was the only active research program in the field at the time, we were starting with a clean sheet of paper and had a great deal of latitude to identify the most important research issues. We were particularly conscious that we were starting on something new that was meant to lead to large changes in transportation, not something that would be incremental or a continuation of "business as usual". This pointed toward research topics that represented significant departures from the mainstream of transportation research at the time, which was only possible because of the visionary leadership provided by John Vostrez at Caltrans.

The first several years of PATH research were divided into three primary categories:

(a) *Navigation* – research on issues related to how enhanced information about traffic conditions could lead to more intelligent traffic management and traveler route choice decisions. This evolved into "Advanced Transportation Management and Information Systems" (ATMIS), reflecting the California preference for integrating public sector traffic and public transportation management with dynamic route guidance for individual drivers or travelers (in contrast to the national program tendency to segregate Traffic Management and Traveler Information as separate functions).

(b) *Automation* – research to determine the technical feasibility and transportation system impacts of automated highway systems. From the start, the highest priority in California was to determine how to achieve a highway capacity increase large enough to get ahead of the growth in population and economic activity, without requiring such huge civil infrastructure additions that it would be unaffordable and environmentally unacceptable. Since the technologies involved here are closely related to the technologies for safety warning and control assistance systems, this area was given the broader name of Advanced Vehicle Control and Safety Systems (AVCSS).

(c) *Roadway electrification* – continuation of the previous RPEV work, to develop and test a viable roadway electrification technology and determine its impacts if it could be deployed on a large-scale basis. This work was important because of the environmental sensibilities in California, political support for the research funding, and the involvement of the private electric utility industry as well as public sector transportation agencies.

The roadway electrification work was terminated after a few years because it was not possible to develop an affordable design for the roadway inductor that was needed to supply power to the vehicles, even after several iterations of design and full-scale testing on the test track. This left two main branches in the PATH research program, ATMIS and AVCSS. The research funding was divided between these areas, in roughly comparable amounts until the advent of the very large new activity of the National Automated Highway Systems Consortium.

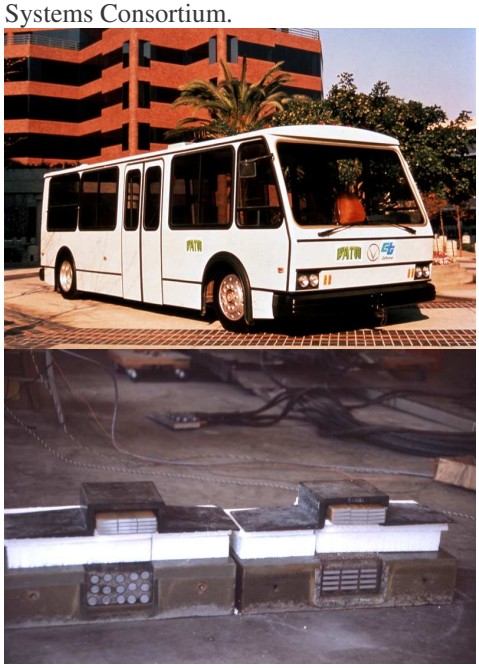

Fig. 2 Roadway-Powered Electric Bus and Cross-Section of Roadway and Onboard Power Inductors

VII. Work on National IVHS/ITS Architecture

The first large project of the national IVHS program was the development of the National IVHS Architecture, stimulated in large part by Bob Parsons' leadership of the System Architecture Committee in IVHS America. Caltrans and PATH were very eager to participate in the project, but recognized that they would need to join one of the teams that were being formed to compete for the U.S. DOT contract. These teams were being led by major corporations, primarily from the aerospace industry, several of which were based in California. Caltrans advertised a competition to select the team that we would join, requiring the competitors to submit written proposals and go through oral interviews. Because of the prominence of Caltrans and PATH in the national IVHS program, most of the leading competitors for the national ITS Architecture program were willing to go through this additional step to gain the Caltrans/PATH partnership on their team. Following an intense competition, Caltrans and PATH chose the Rockwell team as their partner, and continued as members of the Rockwell team through both phases of the National Architecture program.

The work on the National Architecture program provided a good introduction to the mixture of technical and institutional issues that characterize most ITS projects. Indeed, the major focus of the Caltrans and PATH participants in the Architecture project involved ensuring that the institutional issues assumed appropriate weight alongside the technical issues that are more typical of aerospace system architecture work, and evaluating the transportation system impacts of eventual ITS deployments based on the architecture.

California was among the most enthusiastic and persistent advocates of changing the name of IVHS to ITS in order to emphasize the broader multi-modal applications of the systems. It was important that this not just be seen as a program for "vehicle industry" and "highway" interests, but that it address the needs of the transportation system as a whole. PATH changed its own name at about the same time in order to make the same point.

VIII. PATH Research Management Process

Major research universities such as U.C. Berkeley are very conservative institutions, not susceptible to rapid change. Leading faculty members have well-established research programs and generally long-term sources of research funding, and do not commonly jump into new fields with alacrity. So, the advent of the new PATH Program and its research funding from Caltrans did not guarantee immediate faculty involvement on a large scale. Rather, there was a gradual process of introducing the new research issues to key faculty members who had related interests and seeking their advocacy within the faculty. Perhaps the most effective such advocate was Prof. Pravin Varaiya of the UCB Department of Electrical Engineering and Computer Sciences, who subsequently became the PATH Director.

For the first 15 years or so of the program, the most enthusiastic faculty participation came from the Departments of Mechanical Engineering and Electrical Engineering and Computer Sciences rather than from the more traditional Transportation Engineering faculty in Civil Engineering. Indeed, in the mid-1990s the Transportation Engineering faculty was still questioning whether ITS was sufficiently "fundamental" that it should be included in the transportation teaching curriculum or whether it was just a "passing fad for gadgetry". It was still difficult for some to comprehend the basic concept of ITS providing the information linkages that make it possible for the vehicles and roadway infrastructure to operate cooperatively as a well-integrated transportation system. It's hard to get much more fundamental than that.

In the first few years of PATH research, Caltrans gave wide latitude to the University of California faculty and the PATH research staff in defining research topics. This provided significant intellectual stimulation to all involved, as we had the rare opportunity to proactively set research directions rather than merely responding to topics suggested by others. As the program grew larger, a more structured process of research planning and programming was developed and applied. This represented an effective and cooperative merging of the interests of the research community and

sponsors. The annual cycle of project creation and oversight followed this pattern:

Early fall – Annual PATH research conference, attended by about a hundred Caltrans and PATH people, including faculty, students, post docs and research staff. Results of the previous academic year's research are presented and workshop discussions are held to identify candidate topics for next year.

Late fall – PATH research staff draft research problem statements for next year, which are then reviewed and modified by Caltrans, with a few iterations to converge on the statements to appear in the new RFP.

Winter – RFP for new research projects is issued to all universities with relevant departments (primarily engineering) in California, and interested researchers submit proposals for funding. Proposals may be for periods of up to three years and must remain within funding constraints equivalent to no more than three graduate students per year (or one graduate student and one post-doctoral researcher).

Early spring – PATH research staff coordinate academic peer reviews of proposals (choosing at least three reviewers per proposal) and Caltrans staff provide practitioner reviews. PATH and Caltrans staff compare results of the parallel review processes and negotiate over proposals for which their review results are incompatible (typically no more than 10% to 15% of the total proposals).

Late spring – Caltrans/PATH joint management team meets to review results of proposal reviews and prioritize proposals for funding, within constraints of available funding.

Summer – Administrative processes proceed to try to authorize funding of new start projects early enough in the fall semester to provide support for new graduate students.

For much of PATH's history this proposal selection process applied to faculty and student research projects, but not to the permanent PATH research staff. The research staff was established to serve a couple of functions that were incompatible with participation in this proposal process:

- providing the hardware and software support functions needed for large-scale experimental projects;
- developing and leading research projects on topics that were important to the overall research program but were not suitable for faculty and student research or did not receive any proposals good enough to merit funding (known as the "gap filling" function).

In later years, these distinctions between the PATH research staff and faculty were diminished and the research staff submitted proposals through essentially the same process as the faculty. The breadth and depth of capabilities of the research staff have been distinguishing characteristics of PATH since the early days of the program, when it was recognized that it would be necessary to retain dedicated "institutional memory" so that later research work could build most effectively on what was learned from earlier projects.

The competitive peer review process helped to enhance the quality of the research proposals that were submitted and approved for funding, while also helping to balance consideration of proposals from many universities throughout the state. In a typical year PATH projects would be sponsored on as many as ten different campuses, although the largest concentrations of projects typically were found at U.C. Berkeley and Irvine. As the research program grew in size and complexity, it was never possible to develop a large enough research management staff to provide close oversight of individual research projects, so the project leaders retained a great deal of autonomy.

IX. Research on Automated Highway Systems

PATH is the only ITS research program to make a comprehensive, long-term investment in research on automated highway systems (AHS). From the very start of the program, the primary goal was to develop the capabilities needed to make a significant leap forward in reducing congestion, and AHS has long appeared to be the only alternative that could make such a strong contribution. The original sponsors at Caltrans and the original researchers at the University of California saw these opportunities and seized on them. It was surprising to us that few others followed in our footsteps, so we had the field largely to ourselves for quite a few years.

When the U.S. DOT began its IVHS research program, its resources were subdivided according to the "alphabet soup" of IVHS systems. When they looked for partners to work with them on the AVCSS element of their program, Caltrans and PATH were the logical choice, so the first increment of federal funding in this field came to us for research on vehicle longitudinal control, augmenting the state resources that we were already devoting to other aspects of vehicle automation research.

PATH began building its vehicle experimental capabilities in the late 1980s, acquiring the hardware and software support staff, test vehicles, shop facilities and test tracks to enable experiments with vehicle automation technology. The first PATH experiments on the use of permanent magnets embedded in the roadway for vehicle guidance were conducted in 1988-9, proving the ability to detect vehicle position accurately based on magnetic field measurements (7). PATH built a short test track (about 300 m) at the Richmond Field Station in 1991-2 to provide the venue for testing automatic vehicle steering control based on the magnetic guidance concept, and implemented its first automatic steering control on a Toyota Celica that was provided with an electronic steering actuator by IMRA America, Inc. (Fig. 3).

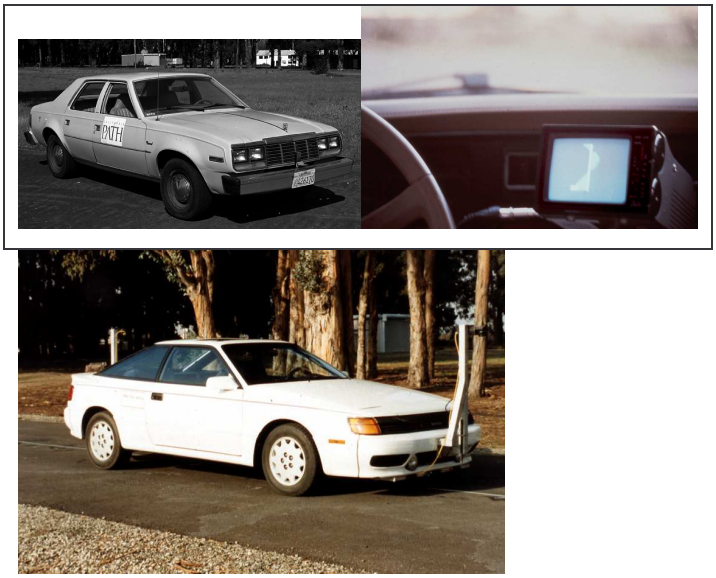

Fig. 3 First PATH Lateral Control Test Vehicles (AMC Hornet with magnetic guidance display and Toyota Celica with IMRA steering actuator and line-scan cameras for independent measurement verification)

In 1989, Ford provided PATH with four vehicles to use as experimental platforms for automatic longitudinal control in a close-formation platoon. PATH equipped these vehicles with throttle and brake actuators, forward ranging radars and wireless LAN communication systems, as well as control computers and software to implement cooperative vehicle following at close separations (8). By 1992, the first vehicle platooning experiments were successfully concluded, and the four-vehicle platoon capability was demonstrated for visitors on the I-15 HOV lanes in San Diego in 1994 (Fig. 4).

Fig. 4 Four-car automated platoon in San Diego, 1994

The ISTEA transportation reauthorization legislation included a provision stating that, "The Secretary [of Transportation] shall develop an automated highway and vehicle prototype from which future fully automated intelligent vehicle-highway systems can be developed….The goal of this program is to have the first fully automated roadway or an automated test track in operation by 1997." This language was inserted by the Chief Scientist of the House Committee on Science, Space and Technology after their Technology and Competitiveness Subcommittee received testimony from me and a few others about the potential opportunities that AHS offered. It became the basis for the creation of the federal research program on AHS.

In the spring of 1992, shortly after ISTEA was passed, DOT invited Caltrans and PATH to join with several of the major automotive companies and suppliers to form a consortium to develop the AHS. After a few months of intensive planning work by all of the invited organizations, DOT concluded that they would not be able to negotiate a contract with this consortium on a sole-source basis and had to revise their program concept. This led to the creation of a quick procurement for the cluster of one-year projects known as the AHS Precursor System Analyses in 1993, while DOT worked on their plans for procuring the larger AHS program. The new AHS procurement was issued in early 1994 and two teams formed to compete for it, one led by General Motors and the other led by Ford and TRW. Because PATH had such a strong track record in AHS research, it was the only organization invited to participate in both proposal teams. This created an interesting challenge because PATH had to form two separate proposal writing teams to work on the competing proposals, with no contact permitted between the members of those teams.

By the fall of 1994, the team led by General Motors won the competition and established itself as the National Automated Highway Systems Consortium (NAHSC). PATH and Caltrans were very active participants in the NAHSC, and indeed PATH devoted more labor years of work to the Consortium than any of the eight other members (approximately 85 labor years, representing 25% of the entire consortium). This represented an opportunity to significantly expand the scope of PATH's research on highway automation in several dimensions, including operational concept definition and evaluation, modeling and simulation tool development and experimental implementation of fully automated driving on a platoon of eight automobiles. The PATH research staff expanded to about 60 people, of whom about half were working on NAHSC research. PATH had the lead role in the NAHSC for the development of modeling and simulation tools, for the second stage of operational concept development and evaluation, and for the demonstration of an automated platoon of eight cars.

The most visible product of the NAHSC research was Demo '97, the highly publicized demonstration of AHS concepts and technologies in San Diego in August 1997. Although many people outside the NAHSC thought that this was the sole focus of the NAHSC's work, in fact it represented less than half of the NAHSC level of effort. Demo '97 received a level of attention from the general-interest media that was unprecedented for an ITS activity, with highly visible coverage from most of the leading national print and electronic media outlets. PATH's platoon demonstration (Fig. 5) was probably the most visible element of Demo '97, providing vivid imagery of the eight automated vehicles following each other in close formation, with one of them changing lanes and shifting its position in the platoon

formation, while the "drivers" waved their hands to show that they were not doing the steering.

Fig. 5 Eight-car NAHSC platoon demonstration in San Diego, 1997

The NAHSC program was originally planned and proposed for a seven-year period, leading to the development and testing of a prototype AHS and the creation of technical specifications. However, the U.S. DOT lost its vision of AHS early in 1997 and decided that it would terminate the program after the 1997 demonstration. The result was that much of the research was interrupted in mid-stream, before it was complete enough to be published. The interim findings from this work were documented in the extensive NAHSC reports to the U.S. DOT, but those reports were never made available to the public, so much of the work that was accomplished and the knowledge that was gained from that work were only known to the direct participants in the program.

The termination of the NAHSC program was a major disappointment at PATH, and forced a significant shrinkage in the size of our research program and staff (fortunately almost entirely by attrition). Caltrans continued to support work on advancing knowledge about AHS concepts and technologies through a variety of research projects and initiatives such as The Phoenix Program and a multi-state pooled fund project on Cooperative Vehicle-Highway Automation Systems. The Caltrans-funded research projects included a major activity to experimentally verify fully automated driving of three transit buses and two tractor-trailer trucks in 2003. A comprehensive review of the state of knowledge of AHS issues for light-duty vehicles, largely based on the PATH research, is available in (9).

The knowledge and experience gained through the cumulative 600 labor years of research that PATH has devoted to AHS provided the foundations for a variety of subsequent research activities in other aspects of ITS, including development and evaluation of several types of collision warning systems, precision docking of transit buses, snowplow guidance and control, the traffic performance measurement system and the development of the cooperative communication capabilities behind the current interest in vehicle-infrastructure cooperation.

X. More Recent Development of PATH

In recent years, the relationship between PATH and Caltrans has been redefined and the research program has been reorganized. The Caltrans research program has shifted to a "customer-driven" perspective, with the priorities set by the mainstream operations and maintenance people in Caltrans rather than those who specialize in research. This means that there is much more interest in near-term, incremental research than in longer-term transformational research. The lead role in selection of research topics for the annual RFP and of proposals for funding has also shifted from PATH to Caltrans.

PATH has been reorganized into four programmatic areas to align with Caltrans interests: traffic operations, transit operations, transportation safety and policy and behavior. Separate presentations at this conference will focus on the current research in each of these four areas. The core research at PATH continues to be the projects sponsored by Caltrans, but PATH researchers are continually seeking opportunities to combine state resources with federal resources to participate in the national ITS research program. This has led to major research projects under the Intelligent Vehicle Initiative, Next Generation Traffic Simulation program (NGSIM), and the newer DOT Tier One ITS initiatives.

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