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Summary of Observations on July 1993 Study Tour to Japan

**Donald E. Orne
Steven E. Shladover**

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1. Introduction

1.1 The purpose of this report is to document some lessons learned during the July 3-16, 1993 tour of Japan and Intelligent Vehicles '93 Symposium attendance by PATH Director Donald E. Orne and Deputy Director/AVCS Program Manager Steven E. Shladover.

The tour was arranged by PATH through Japanese contacts to coincide with the Intelligent Vehicles '93 conference. Most of the contacts were known to PATH either from introductions at various conferences or by visits to PATH offices.

Special attention was given by Orne and Shladover to consider the extent to which interaction with government, academic and industrial officials overseas serves both Caltrans and University program purposes. The conclusion is affirmative that program purposes are served. This conclusion is supported by the following:

- e Acquiring current technical information: a large amount of current information that is not yet in the literature and, more importantly, informal insights that would never be written formally in a report or paper were acquired.
- Learning about others' transportation business priorities: the perspectives were given candidly and in detail ranging by individual company from convictions that most systems must be autonomous to the vehicle for domestic institutional reasons to business concentration on the Japanese market because sales are soft in the U.S.
- e Enhancing PATH's already considerable world stature to increase access to information and to allow joint venture formation: access to corporate level officials for protracted periods and evident desire by some Japanese organizations to work cooperatively with PATH was eloquent testimony that PATH now enjoys a world class image and that image can be used to serve PATH program objectives.
- e While it was apparent that many people we visited in Japan had formed a high opinion of PATH by reading our publications, it was also apparent that they had only a fragmentary view of our activities. By the end of each visit, it appeared that PATH's stature had grown considerably from the exposure.

1.2 The authors' careful review of the tour outcome confirms that carefully selected international interaction is beneficial. The ability to have fairly easy entree to high ranking officials who seem to want to work with PATH is a convincing argument that being part of the international IVHS community is worthwhile.

13 The authors are able to make these statements with confidence because it was obvious that PATH is considered to be a leading program, especially in AVCS which is of great interest to Japanese automobile companies. The PATH program size is larger than most individual programs in Japan. Also, PATH technological development is consistent with, and sometimes ahead of, most Japanese programs. The attention given to the authors was extraordinary. For example, Toyota had three corporate directors and several high ranking engineering managers in attendance all day. Four professors from the University of Tokyo, including the VICS program chairman, spent a whole morning in conference. Honda had a general manager, several top engineering administrators and two engineers from their Los Angeles office present all day. Others were similarly attentive (Aisin Seiki, Nissan, Mazda, MITI, Ministry of Construction).

2 Overview

Some generalizations to support the above positions will be given and these will be followed by a more detailed description of the individual visits and the Intelligent Vehicle '93 Conference.

Government ministries are independent and seemingly at cross **purposes** in their IVHS activities. The principal ministries are Transportation, Construction, Post and Telecommunications, International Trade and Industry and the National Police Agency. The Universities try to play a facilitator/mediator role in bringing these agencies together. Consequently, university professors often chair coordinating committees.

There is generally little joint research between the universities and the automotive companies. A panel of five worldwide automotive companies and one university professor at the Intelligent Vehicle '93 Conference strongly confirmed the often heard view that industry does not believe that academia is near enough to the problem or responsive/timely enough to be useful to them.

Most companies are separately researching machine vision for automatic steering, collision avoidance and autonomous intelligent cruise control. They are investigating both video image processing and stereo vision. A few are investigating *so* called active systems using laser radar. There seems to be much overlap among the projects.

Japanese transportation infrastructure is elaborate, technically sophisticated and widespread. The emphasis is more on rail than highways. Expressways are generally congested and are expensive to use. Tolls are approximately **\$1.00** per mile and gasoline is about **\$4.00 per** gallon. They carry about 67% commercial vehicles. One estimate is that one train track during the **12** or *so* **peak** hours carries about **15-20** times the passengers that an expressway lane carries. The highway detection system still relies heavily on old sonic detectors. By contrast, there are elaborate changeable message signs roadside, in buses and trains and at **bus** stops. This technology is also **used** extensively on billboards. Most are either multi-color LED's or small module magnetic reversible disk units.

There was considerable discussion in several places about the International Standards Organization's recent move to organize international IVHS standards development. Steve

Shladover has been asked to participate by the U.S. It is not clear why Japan has such an elevated interest because some people suggested separate American, European and Japanese standards and the areas needing worldwide uniformity are not evident.

The sections that follow will highlight the individual visits. These are intended to be a discussion of technology and a distillation of particular insights.

3. Monday, July 5 – University of Tokyo

We met with Professors Iguchi, Takaba, Koshi, and Yoshimoto as well as Mr. Fujii of JSK, the Association of Electronic Technology for Automobile Traffic and Driving. These Professors serve as chairmen of the committees that steer most of the IVHS programs in Japan, providing a uniquely broad perspective on the **state** of IVHS in Japan. It was particularly valuable to have their very candid inputs at the start of the trip, because they provided us with the framework within which virtually all the rest of our observations could fit.

The dominant issue in IVHS in Japan is the rivalry among the five competing government ministries that have a stake in IVHS. Given the very strong central government, these ministries are the driving forces, much more so than industry or lower levels of government, especially the two with regulatory roles (National Police Agency (NPA) and Ministry of Posts and Telecommunications (MPT)). Each ministry sponsors its own Association, with funding from industry, but under the direction of the ministry. This seems to be how they achieve public-private coordination.

Other important observations from this meeting included:

- There are about 300 people in total working on IVHS R&D in Japan, but with huge overlap among programs (many people working on multiple programs, doing the same work).
- The role of universities is very different in Japan, compared to the U.S. They do not have the strong research role that we have, while the industrial people are much stronger in R&D. However, the top university people, especially at the University of Tokyo, have unique access to the government ministry people and appear to be the only ones able to broker accommodations among them, as well as serving a "neutral" advisory role to multiple ministries as well as industry.
- Most of ATMS is considered standard practice of long standing in Japan, and is not even a part of IVHS. However, electronic toll collection has not even gotten started because the expressway authority is very conservative about that.
- Freight transportation is a dominant factor on both urban and intercity roads, much more so than in the U.S. More than half of the road vehicles in Tokyo are commercial, partly

because of extreme "just in time" commercial and industrial practices, and also because most passengers (80%) travel by rail. Freight ton-miles within Japan are 51% by truck, 45% by sea and 4% by rail.

- Automated highway studies in Japan are concentrating on underground goods distribution in cities and intercity trucking. The earlier plan for an automated truck facility below the New Tomei Expressway (Tokyo-Osaka) was postponed because of current economic sluggishness and a shorter decision horizon by the Ministry of Construction (MOC).
- Current AVCS and ATIS developments are emphasizing autonomous concepts purely to avoid getting embroiled in jurisdictional disputes among the ministries. From a technical perspective, everybody would like to have cooperative concepts.
- Japanese manufacturers will probably not introduce products such as AICC to the U.S. market ahead of the U.S. companies in order to minimize trade friction.
- Because infrastructure is slow to change, they prefer approaches that put more intelligence on vehicles. Development has to proceed separately for vehicle and infrastructure systems because of the competing ministries, so there cannot be a formal system architecture project analogous to the imminent U.S. effort.
- Japan tends to install systems and then evaluate them later. They do not do a lot of up-front system analysis, design and optimization. This is probably because of the pervasive politics affecting key decisions and the lack of a major aerospace industry.
- New gadgets on cars tend to be "hobbies" for half of the drivers to play with, while the rest are for "fully-loaded" corporate VIP cars.
- The recession has reduced sales of ATIS severely. If the prices can be cut to 1/2 to 1/3 of current levels, the market should be much broader. The current price range is from about \$1400 to \$8400 (for Aisin Seiki's voice plus map system in the Toyota Celsior-Lexus LS-400).

4. Tuesday, July 6 – Nissan R&D, Yokosuka

We were escorted to and from Nissan's R&D center in Yokosuka by Mr. Taro Ishi, the new coordinator of all Nissan IVHS activities. We received briefings from several of their research staff, a tour of multiple facilities and a look at their latest AVCS equipment *car*, for the "Advanced Safety Vehicle" (ASV) program of the Ministry of Transportation (MOT). Issues we learned about here included:

- Nissan has established a Transportation Research Laboratory at corporate headquarters in Tokyo within the past three years to ~~try~~ to study the role of the automobile in the

overall transportation system and to predict future trends in automotive transportation from a very broad perspective. This group coordinates their IVHS work, but most of it is done by other groups such as the Electronics Research Laboratory, which we visited. IVHS is integrated into other corporate activities and does not have clear boundaries to segregate it.

- Nissan has 60-80 people doing IVHS research, plus about another 20 in design.
- e Current Nissan IVHS work covers a broad range, from map displays for navigation to HUDs, truck longitudinal warnings by laser radar, driver alertness detection, and more advanced AVCS research, including conceptual work for platooning and automated driving. They would like to have infrastructure cooperation but are frustrated in this by the problems with the government ministries.
- Nissan is looking ahead to fully automated vehicle operations. They are working on AICC for use at highway speeds (above **30** mph) but not for low **speed use** at intersections because of the difficulty of controlling the **speed** of an automatic transmission vehicle at the lower **speeds**.
- Last month, their car development management switched from a platform-project basis to a functional basis (powertrain, chassis, etc.). They plan ahead for two full product cycles of **4** years each (**8** year horizon).
- e Nissan has had an infrared laser radar collision warning system called "Traffic Eye" on the market for their heavy trucks and intercity buses since 1989. This is intended to reduce the 60% of truck accidents caused by driver fatigue and carelessness, 75% of which are on straight roads. The laser system measures reflection time to estimate distance, and the warning has two levels of urgency for the driver. This product is now considered somewhat out of date, and only 2,000 have been sold.
- Nissan would like to go into automotive radar warning systems, but feels hampered by the lack of a solid frequency allocation from MPT. They have temporary access (5 years) to a 59-60 GHz experimental band, but in the future Japan is likely to settle on 59-64 GHz for warning radar because atmospheric attenuation in this range makes it unsuitable for long-range communication.
- e Nissan is actively working on infrared night vision enhancement ("warm blooded sensing") to help reduce pedestrian accidents (which cause over 30% of traffic fatalities in Japan). They like infrared because it is passive and *can* provide imaging, including in light rain and fog, which they showed us. A prototype will be shown at the Tokyo Motor Show this October, and experiments will be done in the ASV project in 1995. The current emphasis is on the optics, but the image processing problems appear to be very complicated to use this to produce a driver warning. They are aiming for a HUD

display that would impose the image of the pedestrian or animal on the scene seen through the windshield.

- e They have worked with MITI on the **PVS** project, but have not had any successful contacts with roadway infrastructure people although they continue to keep trying.
- e The **AV-1** test vehicle we were shown is a Nissan Maxima with actuators for throttle, brake, steering and shifting, plus a laser radar with mechanical scanning of the mirror. The brake actuation uses the traction control system, with separate front and rear control, while the throttle control is a standard vacuum-based cruise control system. Steering uses a DC servo motor on the steering column and a mechanical clutch (like on our GM test car). Video cameras at front and rear are used for sensing, both lane detection and collision avoidance. For side and rear sensing for lane changing they are evaluating video image processing, laser radar, ultrasonics and the IR range sensors used in the new auto-focus cameras. Laptop computers are used for data acquisition in their experiments, and auxiliary power for all the electronics includes a 1kw generator in the trunk as well as an extra battery to keep the computers alive for **10** minutes after a power loss.
- e Future AVCS development work will include automatic parking and car following at low **speeds** for improving the start-up transients at traffic signals.
- e Nissan's wind tunnel tests **1/4** to **1/5** scale models, with a moving belt to reduce the ground effect. This is the largest moving belt wind tunnel in Japan, and they believe this approach is superior to the suction removal of boundary layer used in many other wind tunnels (including at **USC**).
- Nissan is developing both software and hardware for real-time image processing for vehicle control (following lane markings and avoiding forward obstacles). They *can* recognize lanes up to **60m** ahead, and use the lane information to estimate distances to obstacles.
- e Nissan has developed a driver drowsiness monitor using a video camera that observes the driver's face. When his facial expression changes and eyelids droop, the image processing system detects this and issues a warning. The image processor currently needs a **1/2** second cycle to complete its detection, but this will be accelerated. This prototype system will also be shown at the Tokyo Motor Show. The most effective warning was found to be a combination of audio warning and a menthol scent sprayed at the driver. Drinking coffee and chewing gum were found to be more effective than a buzzer alone, based on experiments in their simple laboratory simulation set-up.

5. Wednesday, July 7 — Tsukuba Science City

We took the train for a ride of about an hour to the north of Tokyo, to visit two government laboratories at the Tsukuba Science City: the Mechanical Engineering Laboratory (MEL) of the Agency of Industrial Science and Technology (AIST) of the Ministry of International Trade and Industry (MITI), and the Public Works Research Institute (PWRI) of the Ministry of Construction (MOC).

Our host at MEL was Dr. Sadayuki Tsugawa, who has visited us at PATH twice within the past two years. He is a pioneer in Japan's IVHS activities, especially in AVCS, and is the one person in MITI with a current interest in IVHS. Very significantly, he told **us** that Japan now believes that their automotive industry is **so** strong (some even thinking that it is **too** strong) that it does not need any more help from MITI. Dr. Tsugawa was the sponsor of the **SSVS** (Super Smart Vehicle System) project, which recently conducted preliminary studies on AHS concepts and technologies.

Dr. Tsugawa gave **us** a very comprehensive briefing on the history of IVHS in Japan, including some extremely interesting videos of early projects with which we were not familiar. His laboratory at MITI has an impressive track record of visualizing new applications of technology and then demonstrating them.

Specific highlights included:

- e A briefing and video on CACS, the precursor to most of today's ATIS projects, and a descendent of the American **ERGS**. Apparently there is only one English-language paper on this program, from a TRB meeting at least ten years ago. CACS proceeded from 1973 design work through a 1977-8 field test with **1000** probe vehicles collecting traffic data and **300** vehicles with a route guidance display system, plus 100 instrumented intersections in Tokyo. Many modern features were apparently included in this project.
- e MITI developed a photoelectric method of traffic data collection, measuring **speed** as well as vehicle presence. However, it was not adopted by MOC or NPA and was therefore not implemented.
- e MEL began their AVCS research in the early 1960s, with a wire-follower automatic steering system that seems to predate the work by Fenton at Ohio State. Not only the steering, but **also** the acceleration and braking, were controlled automatically to maintain a set speed, with no driver on board the vehicle. A "moving block" system using inductive loops in the pavement was demonstrated for vehicle spacing control in 1966, but the project was not pursued because it would have required too much infrastructure investment and there was still no means of detecting obstacles on the roadway. These problems led to a lengthy sequence of research on use **of** machine vision for vehicle guidance and control.

- Dr. Tsugawa briefed the PATH AVCS researchers on his machine vision work during his visit to Berkeley last year, and has provided us with a large selection of technical papers on the subject. He repeated some of that material on our visit to his laboratory, and also showed us the test vehicle, a Toyota Crown of mid-60s vintage, in his "museum". Although much of the technology he showed us is no longer on the leading edge, it was extremely advanced for its time.
- Some more recent work by Tsugawa's group is on the "soft linked vehicle system", which is platooning of vehicles using communication between vehicles as well as dead reckoning and map matching (but no direct sensing of the other vehicles). This has been demonstrated using automated guided vehicles following each other in the laboratory.
- The latest work here is on visual navigation, using a machine vision system to develop a "map" of the vehicle's environment. This is being tested in the laboratory, and the next stage will be testing on a test track using the PVS test van.
- In order to move to the experimental stage of the SSVS project, Tsugawa needs to get external funding from the MITI headquarters or the Science and Technology Agency (Japan's equivalent of NSF) in order to be able to issue subcontracts to private companies. In a typical year, only one or two out of 50 proposals submitted from MEL will receive such funding. On the latest cycle, he has used the American AHS program with the 1997 demonstration as an important part of his justification for funding. The fate of the proposal for next year should be decided by December (with work to start at the April 1 start of the new fiscal year).
- We gave a PATH overview briefing for Tsugawa and some visitors from PWRI and from the Japan Automobile Research Institute, who seemed quite interested.
- We met for about a half hour with Dr. Kenichi Matsuno, the Director-General of MEL. He went out of his way to emphasize the program that they have for hosting international students to work in their laboratory, and encouraged us to have some of our students apply in the next round (which is apparently handled on a government-to-government basis). Knowledge of Japanese is very helpful but not essential, since they offer some language training for the successful applicants.
- Dr. Tsugawa escorted us to PWRI, which is located on the opposite side of town. We were hosted there by Mr. Tetsuo Matsumura, and also met briefly with the assistant director general, Dr. Takashi Iijima. This is a very large institution, covering virtually all civil engineering related disciplines and their application to society by the MOC. They have a cooperative exchange program with FHWA, and have met to compare notes on research areas of common interest. It would seem to be very useful for Caltrans to also be in close contact with them because of the broad areas of common interest (construction research, materials standards and specifications, reduction of traffic noise and pollution, pavement testing, construction robotics, bridge and structure design,

construction management, seismic design, tunnel lighting, etc.). For purposes of our visit, the emphasis was on their limited IVHS-related activities. These include the RACS program in ATIS, an automated guideway bus system similar to the Daimler Benz work, an intersection hazard warning system and a roadway lighting system to warn drivers of oncoming cars on blind curves, an automated urban freight movement system and the ARTS (Advanced Road Transportation System).

- e At PWRI, we were given demonstrations of the intersection hazard warning and roadway guide-lighting systems. These detect vehicles using ultrasonic and infrared sensors, and then use the vehicle presence information to illuminate a sequence of lights around a blind curve ahead of the moving vehicle or to flash a warning on a variable message sign at a blind T-intersection. The systems were impressive in performance, but appeared to be rather expensive to install and operate.

6. Thursday, July 8 – Aisin Seiki Proving Ground

We took the train to Nagoya, where we were picked up by people from Aisin Seiki and driven to their Fujioka proving ground in the hills above the city, not too far from Toyota City. They gave us presentations about several of their AVCS projects and some demonstrations on the track, and we gave them an overview briefing on PATH. Our primary host for the day was Mr. Naoji Sakakibara, who appears to have the job formerly held by Tak Omitsu before he transferred to the IMRA office in Ann Arbor. We were joined for dinner by Mr. Takaaki Nakazawa, the General Manager of Mechatronics System Products and of the Automotive Planning Department, representing corporate decision making management.

Specific items learned here included:

- e Aisin Seiki is seeking new safety relevant markets including use of technologies such as 4-wheel drive, 4-wheel steering, active suspension, lateral control, adaptive cruise control and collision avoidance.
- a The new lateral control approach they are developing uses a laser radar system, relying on reflections off the markers that Caltrans presently installs on the roadway. This requires multiple computers on the vehicle and some touchy high-speed electronics as well. They measure the distance and the azimuth angle to the markers in order to guide the vehicle, which uses a similar steering actuator to the one on the Celica used for our lateral control experiments (but with more safety features built in).
- a They are developing an adaptive cruise control system using image processing to detect lane markings and the range to a preceding vehicle. We were given a demonstration ride on the test vehicle for this system, which followed the lane markings around part of the test course but could not deal with the more abrupt curves. The image processing system has detected the range to within **5%** on straight road and **8%** on curves, but it is only

designed for use on flat road surfaces, not hilly roads. A large, special-purpose image processing computer is used now, with no thought yet given to how this could be done economically for a commercial product. Both throttle and brake control are electronic. The throttle control system is being developed as a commercial product, using a stepper motor to achieve a full stroke of about 80 degrees in 150 ms (probably fast enough for our needs). The braking is controlled using solenoid valves installed directly in the hydraulic brake system, with PWM control for partial braking. They expressed interest in cooperative work with PATH in the brake control area (where we do need to do some work and have no fully satisfactory hardware yet). They said that they have done a trade-off study on different approaches to electronic braking control, and have found the principal concerns to be in the reliability and safety areas. The Camry test vehicle that they have sent to the U.S. for testing has electronic brake hardware in place, but the software has not been developed yet.

- Aisin also mentioned their interest in integrating lateral and longitudinal control, using both sensing and vehicle-vehicle communication. This work was still in the conceptual stage and had not yet been implemented in hardware. Since Aisin is basically a component maker, their emphasis would be on the individual actuator components rather than on the system as a whole (which makes quite a lot of sense).

7. Friday, July 9 – Toyota Higashifuji Technical Center

Mr. **Norio** Komoda, who heads the IVHS activities in Toyota, accompanied us on the train and subsequent limousine ride to the Higashifuji Technical Center, which is Toyota's main proving ground, in a valley near the base of Mount Fuji. We had briefings on several Toyota IVHS activities and a demonstration ride on the test track, as well as a facilities tour, and we gave them an extensive briefing on PATH and TravInfo. A large group of Toyota employees participated in the meetings, most prominently three members of the Board of Directors, who spent virtually the entire day with us. These were Mr. Iichi Shingu, Senior Managing Director and Tokuta Inoue and Masanori Hanaoka, who are respectively the Directors of the Higashifuji Technical Center and the R&D Planning Division (where Komoda works). This level of corporate attention to our visit was very impressive, particularly considering that Shingu and Hanaoka both had to travel significantly from their home bases to participate in the meetings. Because of the high level of the Toyota attendees, the meetings were quite formal and ceremonial, with official opening and closing statements by both Toyota and PATH.

Mr. Shingu's opening statement expressed strong interest in U.S. IVHS activities, starting with Mobility 2000 and extending through IVHS America, with particular interest in PATH. They would like to be able to collaborate with the U.S. IVHS community, and are trying to focus their U.S. IVHS activities to enhance mutual cooperation.

Mr. Komoda reviewed current IVHS activities at Toyota, and in the process shed light on some more of the national-level IVHS work in Japan. Among other things, Toyota is cooperating with

the Advanced Traffic Information Services (ATIS) Corporation, which was founded this month by the Tokyo Metropolitan Police Department together with a group of private companies to provide instant congestion information. They are also involved with the NPA's new Universal Traffic Management System (UTMS) project, which was started in April, apparently as something of a descendent of AMTICS, but still in cooperation with the VICS program.

The Toyota emphasis is primarily on ATIS and AVCS because of their in-vehicle significance. They also have a project within the Toyota Urban Transportation Research Institute on an automated cabin system which sounds a lot like PRT. The major internal IVHS activity is called the VI Project, for Intelligent Vehicle/Infrastructure. This is chaired by Hanaoka, with Komoda as the secretary, and has five technical committees attached to the various R&D divisions of the company. The purposes seem to be promotion of internal IVHS R&D work and coordination of their external cooperative activities, such as representation by Toyota and their affiliates in IVHS America.

- e Toyota is very interested in the ISO TC-204 standardization activities, and raised that prominently in the discussion. Komoda is the convenor (chairman) of the international working group on vehicle control systems, and was eager to discuss those activities based on the assumption that Steve would be one of the two U.S. representatives. We warned him of the necessity of our getting federal funding support for the international travel associated with this work. He assumed that would be a matter of course, based on the way the AIST supports all Japanese participants' travel for ISO activities.
- e There are about 30-40 people working on IVHS R&D at Toyota at this time. This compares to a total employment of about 3000 at the Technical Center in Toyota City and 2000 at Higashifuji.
- e Toyota reviewed the "Super Expressway for Automated Driving" - SEAD 21 project which was presented by Prof. Fujioka at TRB as part of the ARTS program. This is intended as an evolutionary concept for AHS, with automation of the outer lane of an expressway, in mixed traffic, at speeds up to 100 km/hr. Lateral guidance would be by inductive cable, communication would be by leaky coaxial cable and beacons, while obstacle detection would be performed by vehicle-mounted radars and video systems as well as roadside video systems every 200 m along the road. Lane changing and lateral collision avoidance maneuvers would be manual, but all other driving functions would be automated. They used this concept as the framework for presenting some of their specific technical developments toward the "Toyota Automated Vehicle System".
- e Toyota implemented lateral control with inductive sensing of a buried cable on a rough road on the test course in 1989 in order to help out with driveability testing. They are using magnetic sensors at both front and rear of the car to get separate lateral and yaw measurements. The actuators are electric motors on the steering column and shift lever, and hydraulic actuators pulling on the brake and accelerator pedals. Fuzzy control was used to achieve human-like steering, with training by a human driver, and multiple

driverless vehicles were operated independently on the test track, using a central supervisor to keep them separated far from each other.

- In 1992 they added a computer vision system using two CCD cameras and a laser radar system, in addition to the inductive system. The vision system was for an independent lane-tracking function (to enhance reliability), while the laser radar was for vehicle following. It uses a mechanical scan, at 120 ms per scan over +/- 15%, with a sensing range of from 5-120 m, with 10% accuracy. The throttle and brake actuators were upgraded as well, with the throttle being controlled by a stepper motor that needs only 100 ms to open completely (consistent with our needs in PATH), and the brake having a solenoid valve that applies PWM for partial braking, but is capable of applying full braking. The normal operating mode on the test track is a constant 50 km/hr commanded speed. The steering system applies the sum of the driver's input and the actuator input, for a series arrangement somewhat like that used by IMRA.
- e The newest Toyota lane-tracking system is based entirely on computer vision, this time using a single CCD camera and template matching software to recognize lane boundaries. It uses a special machine vision computer from Thomsen in France, and can estimate lateral position to within about 10 cm at a rate of 10 Hz. Thus far, this system has not been used in a control loop, but that stage of testing should be coming up before long.
- e Komoda is actively seeking the most appropriate future directions for AVCS work within Toyota, to try to identify spin-off systems that could be developed as autonomous products without needing the cooperation of the public agencies. He is concerned about the need for extensive human factors research on acceptability of safety and warning systems to drivers and to the public at large. While there has been much discussion about public-private coordination between roadside and vehicle system developments, they have not yet succeeded in achieving any meaningful coordination. They expect heavy-duty vehicle applications to precede those for private automobiles.
- e Testing of the automated systems is done on a reserved 2.6 km test track at the proving ground, with multiple curves in both directions. We were given a demonstration ride on the vision-guided vehicle, using the two CCD cameras. It tracked the lane markings very effectively on several round trips around the track. Although the steering wheel motion was quite jerky in response to the relatively long update intervals between measurements, the ride quality remained generally quite good.

8. Monday, July 12 – Honda Tochigi Proving Ground

We were escorted from our hotel by trains and then by car to Honda's principal technical development center and proving ground at Tochigi, about an hour's ride north of Tokyo, by two of Honda's engineers assigned to their Los Angeles area office, Mr. Yoshiyuki Kimura and Ryoji Igarashi. As at Toyota, this was a very formal, ceremonial visit with a large group of

people and high-level participants (numerous Chief Engineers and the Managing Director for all corporate R&D activities within Honda, Mr. Toru Hatanaka). We received briefings, demonstrations and laboratory tours covering Honda's AVCS activities, and gave them a briefing about PATH, with full translation into Japanese.

Honda is considerably more vertically integrated than the other Japanese auto companies, and appears to do nearly all of their own technology development, right down to the special-purpose computer chip designs and all software. They are not active in sensor systems, which they expected they would acquire from outside vendors, but they have given a great deal of attention to the kind of automatic actuators that we will need for our fleet of test vehicles. Their presentations were oriented around this aspect of their work, and they stated very directly their interest in participating in PATH's work on the development of the test vehicles. They were also very direct about their interest in the national AHS program and the 1997 demonstration, and wanted to know what kind of role they could have in that.

More specific observations from this visit include:

- We were driven from the train station to the test facility by Mr. Kyoka Nakagawa, the developer of Honda's in-vehicle navigation system, who demonstrated it for us on the way. Although this system was designed entirely by Honda, it is manufactured for them by Alpine Electronics. This navigation system was a fairly standard map-based display system, using wheel rotation sensors, a gas rate gyro, and map matching for vehicle location, with GPS for independent verification.
- e Tochigi is the main center for Honda's R&D work, and employs about 4000 people. There is a second research center at Wako, which does more basic research and concept development for future cars, and then several smaller research centers focused around specific product areas such as engines, power equipment and motorcycles and scooters. The Tochigi Proving Ground has **37** km of test tracks, with a wide variety of driving conditions including many kinds of rough roads, very slippery surfaces, etc. for testing under all weather conditions. At the center they have a flat, smoothly paved test course measuring 1500 by 52 m, with 100 m diameter circles at both ends. The main test oval is **4** km long, with three lanes and a maximum **speed** of **200** km/hr in the sharply banked outer lane.
- e More so than any of the other companies, Honda appears to have mastered the transition between their advanced research activities and product development. Their research produces a pool of knowledge, ideas, and concepts, within which the product developers can "shop". They have a well organized process for exposing the product developers to the research results, and they apparently do not have to "sell" these ideas aggressively to the development teams. The development teams work within an overall product development strategy, but appear to be eager to adopt new ideas.

- e Honda has developed an electronic power steering (EPS) system which has been available for several years in the Acura NSX sports car. This system appears to be far ahead of the Aisin/IMRA system used in our experiments, and may be quite suitable for our fleet of test vehicles. They gave us a detailed briefing on the system's operation and showed a cut-away model as well. The EPS was developed to save power and fuel on the vehicle (since it only draws power on demand), to provide more precise vehicle handling for the driver, to provide high reliability, and to enable the steering system to be flexible enough in performance that the car would be easy for the relatively unskilled driver to drive while also providing maximum performance for the highly accomplished driver. The EPS uses an electric motor mounted directly in the front axle to provide a torque assist to the steering system, moving the rack through a ball screw drive. When it fails, the vehicle reverts to normal manual steering feel rather than being completely disabled. Honda believes they have solved the EMI problems that have worried other developers of steer-by-wire systems, and they have obviously devoted a great deal of effort to accommodating the different failure modes in order to ensure system safety.
- e Honda has also developed a drive by wire (DBW), or electronic throttle control, system, which should be in production in two years. This system was developed to simplify the integration of multiple powertrain control functions (cruise control, traction control, idle control), to provide higher reliability, and to provide a more flexible under-hood layout of components (eliminating the throttle cable, for example). The stepper motor mounted directly on the throttle body can provide full throttle opening within 80 ms and an accuracy of 0.1 degree, well in excess of the specs we have identified for our test vehicles. Both the DBW and SBW development at Honda are excellent examples of the development of enabling technologies for AVCS that have been justified entirely for non-IVHS-related reasons, but can contribute significantly to the advancement of AVCS. These are also exactly the kinds of technology developments that the automotive industry people are much better equipped to pursue than our university-based research groups within PATH.
- e Honda is developing a brake control by wire (CBW) as well, but this is not as far into the development process as the other actuator systems. It is the most sophisticated such system we have seen thus far, using continuous pressure modulation by servo valves (not PWM like others), for four-wheel independent braking control. This system has extensive safety design features, as one would expect for a safety-critical function such as braking. Since this appeared to be an inherently costly technical approach, we asked about cost effectiveness and Honda indicated that they had been able to combine standard production spool valves with a linear actuator to get the linear servo valve effectiveness at relatively low cost.
- e The Honda people told us that they were very pleasantly surprised to find university-based visitors such as us asking them questions about cost, reliability and safety issues rather than more theoretical issues. This seemed to convince them that our orientation was very practical and compatible with their central interests.

- e We had a tour of Honda's electronics development facility, where they designed both hardware and software for the in-vehicle control systems (engine, ABS, traction control, etc.). They are using state-of-the-art software and simulation tools, as well as proper software development management approaches (independent verification and validation). They have even designed some of their own custom microprocessors for vehicle use.

It was apparent from this visit that Honda is very seriously interested in the U.S. AHS program and in working directly with PATH. They were extremely curious about our test vehicle procurement, and they have certainly made the most impressive pitch we have seen yet regarding their ability to provide vehicles with the capabilities we need. Their approach to technology and product development is very progressive, and appears to be compatible with our general approach in PATH.

9. Tuesday, July 13 - Mazda Research, Yokohama

Dr. Akihiro Okuno of Mazda Research escorted us from our hotel and then by train and taxi to their research center in Yokohama, right next to Tokyo, about an hour's trip. We spent the day with him and some of his colleagues, receiving briefings on their IVHS related research, laboratory tours, and a look at their most sophisticated test vehicle, MOVER-3. Although we were not asked to give a formal briefing on PATH, we showed our video tape, which attracted considerable interest.

- e The Mazda Yokohama research center specializes in areas such as electronics, human factors and combustion, rather than trying to cover the entire range of topics of interest to the company. For example, they design intelligent sensors and microcircuits, but have the fabrication work done elsewhere. For purposes of IVHS-AVCS research, the relevant work is the research on autonomous vehicles that they have been conducting for about five years in a group that is strong in artificial intelligence, but not necessarily in mechanical or control issues.
- e The first stage of the autonomous vehicle research is now considered to be complete, with the development of three test vehicles of increasing sophistication, but very little testing of the final vehicle. They are now looking ahead to the next stage of research, which they hope will be funded under the SSVS program of MITI, and which they also hope will establish more connection to a cooperative infrastructure. Some of the technology they have already developed for the MOVER-3 vehicle will be transferred to the Advanced Safety Vehicle (ASV) project of the MOT, but the main work on that project in Mazda will be done in Hiroshima because of its nearer-term character (research and demonstration to be done by 1995, with deployment by 2000).
- e We were able to inspect the MOVER-3 vehicle on static display, and to see a video of it in operation. However, there is no test track in Yokohama for a demonstration.

Moreover, the computers had been removed from the vehicle, so it did not appear to be in a condition for any testing or demonstration. This vehicle used video image sensors and artificial intelligence processing to provide autonomous highway cruising. Separate functions were implemented for the perception and cruise planning, but the latter appears to have been done only in a simulator, with displays of warning signals to the driver.

- The MOVER-3 test vehicle has a forward-looking video camera on the roof and two additional cameras inside the top front corners of the windshield to provide stereo imaging. The onboard processing is provided by a network of 11 transputers, although they pointed out that this had not yet been optimized for efficiency. Steering, brake and throttle actuation were all by electric motors, using designs that would not be suitable for a production vehicle. The throttle actuation arrangement was much like that on our Lincoln Town Cars, while the steering was by electric motor mounted to the steering column and braking was by a motor pulling a cable attached to the brake **pedal**. An extra-capacity alternator and extra battery were provided to power the transputers. The vehicle has been tested at speeds up to 60-70 km/hr **so** far in the well-structured highway environment. Although obstacle avoidance has been shown on their video tape, it was fudged somewhat in that the trajectory followed by the vehicle was pre-defined rather than being based on real-time decision making. They expect that an operational system would need vehicle-to-vehicle communication analogous to what we are doing, but no research has yet been done on that.
- We were given a tour **of** the Mazda Driving Simulator, and were able to **see** its video imaging system in operation but not any motion. This simulator is used for very basic human factors experiments on issues involving comfort and safety and identification of drivers' capabilities and responses. Its most prominent feature is a linear motor in the motion base, which permits lateral motion over a **7.2** m range and at an acceleration up to 0.8 g. The driver sits in a very small cabin which has an additional three rotational degrees of freedom, and a projection screen that is barely one meter away from the eye. This provides a field of view of only **68** degrees horizontally. The graphics are generated using a custom graphics computer (Mitsubishi?) and the vehicle dynamics are represented in an Alliant computer.
- The "human technology" group is working on various human factors issues in vehicle design, such as psychoacoustics of the auditory environment and reactions to different vibration environments. This seems to be consistent with a human-centered and rather artistic design approach highlighted in their introductory video presentation and mission statements. Some of this is directed at well-focused issues relevant to IVHS, such as how to maximize driver vigilance after long periods of driving by exposing them to suitable sound and vibration environments.
- We received detailed briefings about the Mazda vision ("Autonomous cruising") system, cruise planner and driving simulator. Most of the issues covered in these were of highly specialized interest, but there were some of more general interest:

- e The autonomous cruising system is intended to provide driver support to enhance safety in a freeway environment, rather than a true AHS application (in contrast of other efforts in Japan). The lane detection system looks ahead in the range of 5-30 m, while the obstacle detection approach appears to be quite similar to that used by Professor Malik of UC Berkeley. Even with the use of the 11 transputer network on the test vehicle, the images can only be processed at about 10 Hz, and the overall lag for a follower to respond to speed changes of the leading vehicle is several seconds (equivalent to a rather slow human driver). The system has not yet been refined to work in adverse weather or lighting conditions.
- e The knowledge-based system for cruise planning tries to replicate human driving behavior, with a separate program for each driving function. The model incorporates multiple state transition diagrams, and appears to resemble Ann Hsu's PATH work in some regards, while also showing considerable similarity to Stengel and Niehaus' work at Princeton. They have not applied any formal methods to test or prove the safety of the combination of driving rules included in their model (81 for situation monitoring, 22 goal decision rules and 44 maneuvering rules for action planning).

Although there is considerable excitement within the research and development areas at Mazda about IVHS, the top corporate management is not expecting much success with products, based on the disappointments of 20 years ago in major projects such as CACS and CVS (Computer Controlled Vehicle System, a very ambitious MITI project in PRT). There is concern about the ability of the government ministries to coordinate national development and to implement the needed public infrastructure.

10. Wednesday-Friday, July 14-16 — Intelligent Vehicles '93 Symposium

After the intensive meetings directly with IVHS research groups, this conference tended to be somewhat anticlimactic. However, it was still worth attending because it remains the only conference oriented towards the in-depth review of research on AVCS technology. It attracts a good mix of European and Japanese researchers, including substantial presentations on PROMETHEUS research that we have not encountered at any other conference. It remains a relatively small meeting, with 152 attendees (87 from Japan), and only one session at a time, so everyone can hear all of the papers. The participants are high quality researchers, who *can* provide excellent insights in the informal discussions at breaks and meals.

The highlight of the Symposium was a panel discussion session featuring leading industrial figures in AVCS from Toyota, Fiat, Volvo, Daimler Benz and Nissan discussing the challenges involved in connecting the research done at universities and institutes to the real-world needs of industry. The opening comments of Dr. Ulf Palmquist from Volvo were particularly illuminating. Palmquist adopted a cynical tone to present his material, which he said was a fair representation of the views of the PROMETHEUS companies as a whole. Nobody disputed his

contrast between the academic and industrial research approaches, which clearly illustrates the inherent difficulties faced by a program such as PATH. We have a virtually unique opportunity to bridge the culture gap identified by Palmquist. If we retreat into the "ivory tower" and fail to integrate our work thoroughly with the rest of the world, we are likely to suffer the fate of the basic research programs within PROMETHEUS (PRO-CHIP, PRO-ART, PRO-GEN), which have lost the confidence of the funding authorities and have had their funding cut off prematurely.

Other comments from this discussion session included:

Stefan Hahn (Daimler Benz) — Problems with academic research are primarily (a) their new methods cannot always be used directly by industry, and (b) competition between academics makes it very hard to form collaborative groups.

Ichiro Masaki (MIT, GM) — Academics start with ultimate, exotic and high-cost solutions, while industrials start with low-cost, low-tech solutions. A healthy mixture of both is needed.

Norio Komoda (Toyota) — He welcomes academic research, with pioneering ideas, strong curiosity and independent intellectual leadership. However, academics normally overlook concerns of reliability, cost and time and don't do enough work on human factors. He would expect to have research contracts between industry and universities at all stages prior to product development.

A. Saroldi (Fiat) — There is a need for applied research, and more commonality between research interests of industry and academia. This symposium showed significant differences in the topical focus of industrial and academic papers. They need simple systems on cars initially, with simple user interfaces, and more research on the human factors issues.

Yoshihiko Kimura (Honda) — Cooperation with academia works well for Honda, and they would like to have more of it. The key to success is in selection of good research topics.

Too many of the papers at the Symposium were on micro-detailed computer vision studies that depended on computational resources too burdensome for practical use in the foreseeable future. Some of the European papers about use of machine vision to interpret roadside signs were among the more extreme cases of this. On the other hand, there were some excellent application oriented papers from the European auto makers. Highlights from the presented papers included:

- **Stefan Hahn of Daimler Benz** presented some of the results of their work on simulation of AHS operations, covering much of the material he reviewed during Steve's visit to **D-B** last November. However, some newer experiments for automation of driving in stop-and-go urban conditions indicated that it was very difficult to have a single level of driving aggressiveness work effectively for a wide range of drivers, although the vast majority still thought the technology was useful (**63%**) or very useful (**32%**). They also

found it to be essential to give the driver positive acknowledgment that control has been returned to him (for example if he inadvertently tapped the brake or turned the steering wheel).

- e **Ulf Palmquist** described Volvo's work on an AICC system that is coordinated with the traffic control infrastructure (very much along the lines of a major element in our Research Center of Excellence proposal). Volvo has experimented with a wide range of sensors, including single and multiple beams and scanned beams, as well as transponder based system. They have used a single beam 94 GHz radar as well as multiple beam radars in the 77-78 GHz range that the Europeans are standardizing on. They believe that target selection should be automatic, and the driver should then be informed of the system's operating status (on or off, set speed, target following or not, out of range, etc.). The current sensors look ahead for 100-200 m range, covering three lanes, but they would like to look 300 m ahead for use on the German autobahns. They expect radar to be more expensive than infrared, but to provide more information under a wider range of conditions.

They have not done the throttle and brake actuator development themselves, but have relied on suppliers such as Bosch. Their latest demonstration vehicle uses a five-beam infrared sensor, together with antennas for short range communication of traffic condition information from roadside beacons, using the 5.8 GHz standard that has been developed for road pricing applications in Europe. They have a test track for safety-related tests, as well as a 3.5 km long street in Gothenburg with six equipped intersections, all as part of the Test Site West Sweden. The availability of vehicle-roadside communications here enables them to adjust speed for traffic conditions and to implement "green wave" signal control.

- **Saneyoshi of Subaru** described a 3-D image recognition system (stereo) for driver assistance, which has been programmed to provide the driver with an alarm at 105 m range and braking at a 65 m range when traveling at 100 km/hr. The rationale for selecting these ranges was not made clear. The video he showed indicated good target recognition capabilities traveling on a 300 m radius curve, at night and when going in and out of a tunnel with strong lighting contrasts.
- **The Fraunhofer Institute** described a "driver's warning assistant for intersections" using machine vision. This turned out to be much less than advertised, because it simply used the difference in paint striping at an intersection to identify the location of the intersection, rather than making use of any real-time information about crossing traffic.
- e **The CNRS from France** described the dynamic data management system for the "ProLab II driving assistant", developed under PROMETHEUS' PRO-ART program by researchers from nine French institutes and the two French auto companies. This system uses seven video cameras plus numerous computers with data fusion software to provide real-time diagnoses of the state of the vehicle and all its surroundings. It will be

demonstrated at the November 1994 PROMETHEUS demonstration near Paris. Unfortunately, the presenter had such a heavy accent that it was extremely hard to understand much of the specifics of this project.

- **Dr. Takahashi of Nissan** reported on an evaluation of drivers' reactions to ease of driving a vehicle with different longitudinal response characteristics. This work combined multiple ARMA models and a fuzzy reasoning knowledge base in an attempt to develop fuzzy control laws for a continuously variable transmission (CVT) that would have desirable performance for the driver.
- **Dr. Arain from Lucas** gave a paper on use of neural networks for collision avoidance maneuver planning. The more interesting part of the presentation, however, was the description of the performance of their radar sensor for AICC applications. This is a 94 GHz FM-CW radar, with a beamwidth of 3.5 degrees horizontal and 2.5 degrees vertical. Its range is 2-127 m, with a 1 m resolution and 0.5 m accuracy and an update rate of **40** Hz. It can measure velocity differences of up to 70 m/s with a resolution of 0.27 m/s and accuracy of 1.4 m/s at an update rate of 5 Hz.
- **Dr. Saroldi from Fiat** described their work on AICC and collision avoidance under the PROMETHEUS ALERT project. They are starting with separate development and testing of individual safety functions, and will then develop higher-level communication between subsystems before fully integrating them. The individual subsystems could be turned into stand-alone products along the way, generating a revenue stream. There are four integrated demonstration vehicles: (a) vision enhancement; (b) "Iter-link" for communication and navigation; (c) ALERT for AICC and collision avoidance; and (d) vehicle control assistance. Each vehicle has the same vehicle area network (VAN) for communication among subsystems, each of which has its own processor. The collision avoidance sensing is a microwave system, while the AICC uses laser radar (lidar) and beacons for roadside commands. Future developments will include blind spot warnings, video lane following and radar for operations in fog (94 GHz initially and then 77 GHz in the future).

Fiat's "parking aid" for rear-obstacle detection would be based on a microwave transceiver in the bumper, with a 300 cm range and 10 cm accuracy., but has not yet been tested. The lidar sensor uses mechanical scanning of the beam with a mirror, and its performance and range are the principal current limitations. The braking would be full authority, up to a complete stop. The driver would have a HUD and audible warning for safety critical messages, while routine operating status messages would be on an LCD display in the dashboard. The control system design has been developed using sophisticated software tools, but this remains work in progress with no testing yet on vehicles.

- e **Prof. Graefe from the University of the Bundeswehr in Munich** reviewed the four years of machine vision research that his group has conducted under PROMETHEUS funding, which is one of the most highly regarded accomplishments internationally in AVCS. Much of their work has been implemented on Mercedes test vehicles. The most interesting observations were those he made in response to questions about the most difficult problems he had encountered in his research (shadow discrimination, detection and rejection of false alarms about obstacles, reflected sun off wet roads blinding the cameras) and the most surprisingly easy (object detection).
- e **Dean Pomerleau of Carnegie Mellon University** reviewed the use of neural networks for autonomous vehicles, with a particular focus on applications at CMU. In his own research, they are processing ten frames per second on a Sparc 10 machine, which has been used to steer a vehicle traveling at speeds of 120 km/hr for up to 150 km on a public highway. With an eventual single chip implementation he believes they can reduce cost and increase speed, which already seem to be better than most other vision-based systems. This was the only paper to offer quantitative measures of steering effectiveness — an average lateral error of 1.6 cm compared to 3.2 cm for the human driver used to train the system, and a standard deviation of 7.2 cm compared to 5.5 cm for the human driver. Under one of the ARPA TRP proposals, they will be working with the University of Minnesota and the Graefe/Dickmanns group from Munich to do a direct comparison of the effectiveness of their two competing approaches (which seem to be the two leading vision-based systems in the world today).
- e **Bimal Mathur of Rockwell and Ichiro Masaki of MIT** both reported on research using custom-designed analog chips inside the video cameras to perform pre-processing of the video images, to save speed, cost and complexity in the implementation. Both appeared to have some promise.
- e **Michel Parent of INRIA in France** reported on his multi-stage project DEDALE to develop small urban or station cars, using electric propulsion and eventually also using automation technology for controlling the empty backhaul operations. This would be a modified application of platooning technology, with a human driving the lead vehicle but the following vehicles all tracing the trajectory of the lead vehicle at spacings of 2-3 m and speeds of 50 km/hr. He visualizes automatic driving on electronic highways in ten years, and fully automated operations in mixed traffic after that. His project has substantial funding and support from Renault, EDF (national electric utility) and CGE (transit operations). There will be a 1995 demonstration of 50 station cars, without automation, at Renault's research center at Rueil Malmaison, outside Paris.

11. Conclusions

Two weeks in a foreign environment is hardly enough exposure to draw sweeping, meaningful conclusions yet one returns feeling saturated with new knowledge and an urgency to turn that to practical actions. This led the authors to ~~try~~ to capture as much as possible of factual information and impressions to serve the **PATH** program with **a** lasting reference and a recommendation to move forward in several areas.