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PATH ATMIS
State of the Research Annual Report
Fiscal Year 1999 / 2000

Robert Tam

California PATH Working Paper
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Report for MOU 300

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**PATH ATMIS
State of the Research
Annual Report
Fiscal Year 1999 / 2000**

**Robert Tam
University of California, Berkeley
PATH**

October 4, 2000

TABLE OF CONTENTS

1. INTRODUCTION.....	1
2. DATA COLLECTION SYSTEMS.....	1
MOU 353 – REAL-TIME ALGORITHMS FOR TRAVEL TIME, O-D ESTIMATION, INCIDENT DETECTION AND VERIFICATION (BERKELEY HIGHWAY LAB).....	1
MOU 352 - AUTOMATED TRAVEL TIME MEASUREMENT USING VEHICLE LENGTHS FROM LOOP DETECTOR SPEED TRAPS.....	2
MOU 336 - SECTION-RELATED MEASURES OF TRAFFIC SYSTEM PERFORMANCE: FIELD PROTOTYPE IMPLEMENTATION.....	2
MOU 3008 - FIELD INVESTIGATION OF ADVANCED VEHICLE REIDENTIFICATION TECHNIQUES AND DETECTOR TECHNOLOGIES	4
MOU 350 - VIDEO-BASED SIGNATURE ANALYSIS AND TRACKING (V ² SAT) SYSTEM.....	5
MOU 3005 - DEVELOPMENT OF A REAL-TIME LASER-BASED DETECTION SYSTEM FOR MEASUREMENT OF TRUE TRAVEL TIME ON THE HIGHWAY	6
MOU 378 - INVESTIGATION OF VEHICLES AS PROBES USING CELLULAR PHONES AND THE GLOBAL POSITIONING SYSTEM.....	7
MOU 3015 – FIELD OPERATIONAL TEST OF GPS AND CELLULAR TECHNOLOGIES FOR VEHICLE PROBES	8
MOU 382 – DEVELOPMENT OF A COST-EFFECTIVE SURVEILLANCE SYSTEM FOR DISTRICT 4	8
3. TRAFFIC MANAGEMENT SYSTEMS.....	9
MOU 354 - INCIDENT MANAGEMENT: PROCESS ANALYSIS AND IMPROVEMENT	9
MOU 356 - EFFECTS OF INCREASED CAPACITY ON CONGESTION.....	10
MOU 3004 – ACCESS CONTROL STRATEGIES TO MANAGE TRAFFIC BACKUPS AND INCREASE SYSTEM CAPACITY	11
MOU 3011 - EXAMINING HOW ATMIS CAN INCREASE FREEWAY BOTTLENECK CAPACITY	12
MOU 3007 - DEVELOPMENT OF TOOLS TO ASSESS THE EFFECTS ON TRAFFIC SAFETY OF CHANGES IN TRAFFIC FLOW CONDITIONS UNDER ATMS OPERATIONS.....	12
MOU 3013 - DEVELOPMENT AND EVALUATION OF ADAPTIVE RAMP METERING	13
4. TRAVELER INFORMATION SYSTEMS.....	14
MOU 348 – EVENT-BASED ATIS: PRACTICAL IMPLEMENTATION AND EVALUATION OF OPTIMIZED STRATEGIES	15
MOU 363 – CONSUMER RESEARCH ON ATIS TECHNOLOGIES	15
MOU 364 – FINANCING PLAN FOR PUBLIC SUPPORTED ATIS.....	16
MOU 365 – TRAVINFO EVALUATION, TIC STUDY	17
MOU 3003 - ATIS FOR GROUND TO AIR CONNECTIVITY	17
5. PUBLIC TRANSPORTATION SYSTEMS.....	18
MOU 380 - CARLINK I EVALUATION.....	18
MOU 3009 – EXPANDED, YEAR-TWO CARLINK II PILOT: A USER, ECONOMIC, AND INSTITUTIONAL EVALUATION OF SMART CARSHARING	19
MOU 340 - SAN GABRIEL VALLEY SMART SHUTTLE TECHNOLOGY FIELD OPERATIONAL TEST EVALUATION.....	21
MOU 398 – DEMAND RESPONSIVE TRANSIT SERVICE CONSUMER RESEARCH	23
MOU 3002 - EVALUATING THE IMPACT OF ITS ON PERSONALIZED PUBLIC TRANSIT.....	24
6. DECISION SUPPORT.....	25
MOU 3001 - EVALUATION METHODS FOR MEASURING THE VALUE OF ITS SERVICES AND BENEFITS FROM IMPLEMENTATION	26
MOU 3012 – FREEWAY PERFORMANCE MEASUREMENT SYSTEM, PHASE II	27
MOU 355 - ITS EVALUATION WEBSITE	28

MOU 381 – INTEGRATING A COMPREHENSIVE MODAL EMISSION MODEL INTO ATMIS TRANSPORTATION
MODELING FRAMEWORK 29

7. REFERENCES..... 31

1. Introduction

This report summarizes PATH ATMIS research for fiscal year 1999/2000. In each of the brief project descriptions we state the objectives of the project and outline its status and some of its principal results. These descriptions are not intended to be comprehensive or complete, but rather to present a picture of the main thrusts of each of the reported projects. References are provided in the end of the report for more detailed information about particular projects. Taken together, the collection of project descriptions should give the reader an overview of the entire ATMIS research program. In general we have described only projects which are completed or have produced specific results and reports, and thus a number of projects in progress are not cited.

The report is organized into the following research topics:

- **Data Collection Systems**
- **Traffic Management Systems**
- **Traveler Information Systems**
- **Public Transportation Systems**
- **Decision Support**

2. Data Collection Systems

An Intelligent Transportation System (ITS), by definition, involves the use of intelligence to enhance the operation of the transportation system. To have intelligence of the system, one must have data on the state of the system. This is why PATH has put a premium on the research of data collection. The primary data travelers want to know is their travel time for their trip. PATH has investigated numerous techniques to measure and estimate travel times from various sensors such as loop detectors, video cameras, lasers, and vehicles as probes. Most of the techniques have been field tested in one form or another independently. The research and field tests are described below.

MOU 353 – Real-Time Algorithms for Travel Time, O-D Estimation, Incident Detection and Verification (Berkeley Highway Lab)

Alex Skabardonis, University of California, Berkeley

Efforts to set up a facility, known as the Berkeley Highway Lab, began in September 1997 and finally bore fruit this year. PATH has mounted 12 fixed video cameras and 2 pan/tilt/zoom cameras on the top of a 320 foot high condominium adjacent to I-80 in Emeryville. The fixed cameras provide a continuous view of I-80 between the Bay Bridge approach and University Avenue, over 2 miles of freeways, interchanges, and frontage road. Video tapes for this section of I-80 are being created every weekday. The video from the pan/tilt/zoom cameras is being transmitted via radio modem directly to PATH Headquarters, where it can be used for observing traffic directly and for deciding

when to activate the video tape recorders, which can be controlled remotely. The video will be used for research in video image processes and traffic dynamics. The video will also provide the ground truth for testing different surveillance methods.

It is anticipated rich benefits will result in development of new surveillance methods, understanding of traffic flow, and evaluation of the performance of simulation models in the coming year from the Berkeley Highway Lab. Other research is taking place in this section of I-80, which can be supported by and possibly integrated into the Berkeley Highway Lab. PATH researchers are using double loop detector data from this section of highway to estimate travel time, and other surveillance methods such as video-based algorithms may be tested here as well. Caltrans District 4 is in the process of simulating this section of I-80 using Paramics, a microscopic traffic simulation model. The video will enable testing of how well simulation models match reality.

MOU 352 - Automated Travel Time Measurement Using Vehicle Lengths From Loop Detector Speed Traps

Michael Cassidy, University of California, Berkeley

This research resulted in the development of three closely related algorithms to match a vehicle's length measurement at a downstream detector station with the vehicle's corresponding measurement at an upstream station. The algorithms rule out unlikely matches and look for sequences of possible matches between measurements at the two stations. The algorithms were used to measure travel times on a large data set and the average measurement error for the different algorithms ranged between 0.7 percent and 4.5 percent, corresponding to an average segment velocity error between 0.4 mph and 1.5 mph. The beauty of the approach is in its simplicity. Matching vehicles between detector stations is a difficult task and some of the best minds have tried to tackle the problem with varying degrees of success. Preceding work emphasized computationally intensive strategies and/or hardware intensive strategies. By creating the solution space of possible matches, this research has enabled vehicle reidentification using existing detector hardware and inexpensive computers.

The contribution to the field of traffic surveillance should prove to be significant since the vehicle reidentification algorithms will allow the study of travel time applications without deploying an expensive detection system and thereby enable cost-benefit analysis before investing in a new detection system. If travel time measurement proves to be beneficial, the system could be deployed using speed traps, or the algorithms could be transferred to emerging detector technologies with better measurement resolution. The methodology should prove beneficial for research purposes as well; yielding better insight into vehicle dynamics between widely spaced detector stations without the host of assumptions necessary with simulation.

MOU 336 - Section-Related Measures of Traffic System Performance: Field Prototype Implementation

Stephen Ritchie, University of California, Irvine

With the existing widespread use of inductive loop detectors (ILDs), Intelligent Transportation Systems (ITS) have a constant source of information on traffic system conditions. However, ILDs typically provide only point measures of traffic characteristics such as volume, occupancy, and depending on the loop configuration, local speed, which are inadequate for many ITS applications. If these detectors could be used in a “smarter” way, more useful information could be obtained for important ITS applications in traveler information and route guidance systems, congestion monitoring and incident detection, and traffic control via freeway ramp meters, surface street signals and changeable message signs. One technique to obtain significantly more information from ILDs is to utilize the vehicle waveforms that are produced when each vehicle passes over a loop. Such waveforms are essentially “signatures” that can be reidentified at downstream stations, and yield more useful information such as real-time section travel times, section speed, and section density, as well as vehicle classification and origin-destination data.

In this project, a prototype field implementation was completed in which a vehicle reidentification algorithm based on loop signature analysis was developed using freeway traffic data. This algorithm was extended to non-freeway cases, initially using a section of 2-lane major arterial in cooperation with the City of Irvine, California. The technique was enhanced to address problems such as “irregularities” in vehicle signatures associated with trucks, tail-gating vehicles and erroneous counting of vehicles, with the objective of obtaining 100% correct counts at each station.

The enhanced algorithm was also applied to an instrumented signalized intersection in Irvine to acquire data for real-time congestion monitoring, incident detection and level of service measurement. In order to achieve more reliable vehicle reidentification results, additional routines for vehicle movement filtering at each downstream station were applied. 2070 controller software limitations were found after extensive field tests. Reidentification results based on a small dataset showed an encouraging matching result of 84.07% overall.

Speed estimation from a single loop signature was one of the applications investigated. For several study sites, using speed estimated from a single loop speed, the matching rates were over 70%. In another application, vehicle classification using a Back Propagation Neural Network showed an 80 % classification rate overall for all vehicle types. Heuristic approaches to vehicle classification also demonstrated good results.

This study presented a new framework that is capable of estimating accurate section-based measures of traffic performance such as section travel time and section density from conventional inductive loops. This research also has shown that low-cost enhancements to the preexisting traffic surveillance infrastructure can be an economically attractive means of obtaining expanded and more accurate travel information. Applications of vehicle reidentification show encouraging results for direct use in providing network-wide travel information.

MOU 3008 - Field Investigation of Advanced Vehicle Reidentification Techniques and Detector Technologies

Stephen Ritchie, University of California, Irvine

Research in Intelligent Transportation Systems (ITS) addresses various transportation needs such as efficiency, safety, environmental protection, mobility, and economic viability. In order to fully exploit the advantages of ITS strategies, accurate and appropriate data need to be collected from the transportation network. Therefore it is vital to develop advanced surveillance systems that can properly support the objectives of ITS.

This research proposes the use of the latest technologies available for traffic detection for collecting more accurate traffic characteristics and traffic data necessary for ITS applications, but which are difficult to obtain. The primary traffic characteristic that this research attempts to measure more accurately is section (or trip) travel time. Travel time has been identified by Caltrans as particularly important for assessing traffic system performance. In addition, real-time traffic measures such as dynamic origin/destination demand fractions, lane changing, and section densities can be obtained with a vehicle reidentification approach. This project consists of three major components, based on fully instrumented freeway and signalized intersection sites in the California Advanced Transportation Management Systems (ATMS) Testbed in Southern California.

This project began in January, 2000. The first component of this project is a field investigation of several emerging and advanced freeway detector technologies developed by the PATH program, including laser and/or video detectors, and a particularly promising new detector named the Embedded Differential Inductance Scanning (EDIS) detector. The EDIS detector has a much higher resolution than regular Inductive Loop Detectors (ILD's) and addresses many of the shortcomings of ILD's.

The second component involves utilization of an ILD-based vehicle reidentification system (that was implemented in MOU 336) at a major signalized intersection, to develop capabilities for on-line real-time intersection level of service estimation. The intersection of Alton Parkway and Irvine Center Drive (Alton / ICD) was selected for the study site because it was equipped with double loops on all four approaches. Real-time data transmission is available from the Alton / ICD intersection to an Irvine Transportation Center PC. On-line real-time operation and development of a Graphical User Interface for the vehicle reidentification algorithm are underway. Four City of Irvine intersection cameras are also currently being configured at the intersection to transmit video data to UCI laboratories.

The third component involves an investigation of the fusion of the various advanced detection systems that have been developed by the PATH program (as well as the EDIS detector) for the purpose of vehicle reidentification (or tracking vehicles from one site to another). For simplicity, the feature vectors particular to a single detection technology can be called intra-vectors, while the feature vectors combined across detection technologies can be called inter-vectors. Until now, each advanced surveillance system

has been researched independently. Also, vehicle reidentification has been studied using feature vectors from a single type of detector – intra vectors. However, to improve reidentification performance and thus the estimation of section-related measures of traffic system performance, such as travel time, the feature vectors derived from different detectors can be fused to produce a more robust reidentification system. The trade-offs between cost, accuracy, mounting requirements, and performance therefore need to be investigated for various detector combinations in the context of vehicle reidentification for travel time estimation, as well as other surveillance requirements specified by Caltrans. In addition, the investigation in this research of “optimal” multi-detector feature vectors, that combine detection attributes from several detectors, could guide Caltrans and others in the development of future new detectors that best meet Caltrans’ needs. The combination of various advanced detection technologies will likely yield new, and more accurate, forms of data that are helpful for the development and calibration of improved traffic flow theories and models.

MOU 350 - Video-Based Signature Analysis and Tracking (V²SAT) System

Arthur MacCarley, Cal Poly San Luis Obispo

The Video-Base Signature Analysis and Tracking (V²SAT) System was conceived in 1995 by Loragen Systems, of San Luis Obispo, California, as a means for non-intrusively tracking individual vehicles on freeways for data collection purposes. The concept involves the use of computer vision methods to make simple optical measurements on digitized real-time images of each vehicle on the freeway. A conventional color video camera serves as the primary sensor. Detection modules are placed directly above traffic lanes on an overcrossing or similar support structure, with one detector for each lane. For each passing vehicle, a numeric Video Signature Vector (VSV) is generated and transmitted by the detection module to a central correlation computer, via a low-power wireless network. The correlation computer continuously receives VSV’s asynchronously transmitted by all detection modules, and attempts to match VSV’s to re-identify vehicles at each detectorized site, in order to determine the progress of each vehicle through the freeway network.

In Phase I, two identical portable field data acquisition systems were designed to permit the synchronized recording of video images of vehicles flowing beneath two successive freeway overcrossings. These were used at three pairs of test sites along US Highway 101 in the Central Coast area of California. Each pair of sites consisted of two accessible overcrossings separated by approximately 0.5 miles. Field tests were conducted over a range of traffic conditions and times of day. Data sets were segregated by four test conditions, corresponding to four ambient lighting conditions: overhead sun (mid-day), 45 degree sun (afternoon), reduced light (dusk), and low light (night). For each test condition, VSV’s were compared for each vehicle at the first site with every vehicle at the second site. Correct self correlation matches were observed for 97.27% of all vehicles at mid-day, 98.89% in the afternoon, and 95.15% at dusk. False correlation matches occurred for 0.22% of all possible vehicle pairings at mid-day, 1.66% in the afternoon, and 2.02% at dusk. For daylight conditions, we also assessed the relative value

of color as a VSV component, and the relative value of restricting vehicle comparisons at successive sites to a “reasonable time of arrival window”. The additional color information was found to increase correct matches from 98.3% to 99.0% and reduce false matches from 5.4% to 0.3%. The restriction to “reasonable time of arrival window” was found to add almost no additional accuracy beyond the addition of color information for either metric, although we do not consider the sample size in this test large enough to be statistically sound.

At low scene illumination levels such as those encountered at night, the VSV was found to be difficult and sometimes impossible to measure, with accuracy falling to 75.49% correct matches and 27.05% false matches (without arrival window). General conclusions from Phase 1 were that the VSV is a reliable and repeatable means for the characterization and successive re-identification of vehicles under daylight and transitional illumination conditions. The VSV is unusable if the illumination level is inadequate to produce an acceptable video image.

Phase 2 involved the development of an experimental platform for machine vision-based detection of the vehicle characterization vector components. Four experimental automated detection modules were designed, fabricated, programmed, debugged, calibrated and laboratory tested. The availability of these units made possible concurrent detection and tracking across all lanes at two consecutive sites on a four-lane freeway. A single correlation engine (server) was developed to receive and correlate real-time data from the field detection modules. These units were field tested under actual freeway conditions by the Cal Poly Transportation Electronics Laboratory to assess accuracy and robustness in detection and re-identification of individual vehicles.

Test sites were overcrossings, with detector placements vertical looking down at heights of 24 to 28 feet above the road surface. Communications between units at each site and the correlation server were wireless modems. Field test were performed using two lanes at each of two detection sites separated by approximately 0.34 mile. Results generated by the system in real time were compared off-line against manually verified results from video tapes. Self-correlation accuracy, or the ability to correctly re-identify vehicles at successive sites, was 93.6%. False-correlation errors, or the tendency of the system to incorrectly match different vehicles at successive sites, was 0.0116%. Finally, the basic ability of the system to generate valid vectors for each car was assessed. This is referred to as presence detection accuracy, and was found to be 97.0% over all vehicles, including some for which a reasonable VSV cannot be generated such as a motorcycle or large tandem truck.

***MOU 3005 - Development of a Real-Time Laser-Based Detection System for
Measurement of True Travel Time on the Highway***

Harry Cheng, University of California, Davis

A field prototype has been developed for highway testing of a laser-based non-intrusive detection system for real-time measurement of moving vehicles, based on previous

research on the laboratory prototype of the system. The primary goal of this project is to develop a roadway detection system that can be used to gather reliable travel time data non-intrusively. The system uses a laser line that is projected onto the ground as a probe. The reflected light is collected and focused into a photodiode array by an optical system. Vehicle presence is detected based on the absence of reflected laser light. By placing two identical laser/sensor pairs at a known distance apart, the speed of both the front and rear of a vehicle is measured based on the times when each sensor is triggered. The length of each vehicle is determined by using these speed measurements and the residence time of the vehicle under each sensor.

Several tests have been done with the field prototype system on the highway, and the test results further verified that the principle of the detection system is technically sound and indicated that the algorithm implemented in the software works in most cases. The software for the real-time data acquisition, data processing and graphic user interface has been developed in a real-time operating system. From the software, the speed, acceleration, and length of a detected vehicle can be calculated and displayed simultaneously. The measurement and calculation of laser power has been performed to ensure that the laser system is safe to expose to the public during the field tests and future operation on the highway.

MOU 378 - Investigation of Vehicles as Probes Using Cellular Phones and the Global Positioning System

Y.B. Yim, PATH

The purpose of MOU 378 was to evaluate cellular and GPS technologies for the vehicle probe concept in the San Francisco Bay Area. The project investigated the capability of cellular technologies and the global positioning system (GPS) for traffic surveillance systems. Current traffic travel time estimates are largely based on road sensors embedded in the pavement. Technical developments in cellular positioning and the spread of wireless phones provide the opportunity to track cell phone equipped drivers as traffic probes.

The Federal Communication Commission Phase II mandate for Enhanced-911 (E-911) requires that wireless carriers must provide the location of a 911 wireless call by October 1, 2001 to the Public Safety Answering Point (PSAP), within approximately 125 meters, or under one-tenth of a mile in the majority of situations. The prospects appear to be strong that a solution offering an accuracy of about 100 meters will be developed in close to the time frame demanded by the FCC.

The technical issues of cellular positioning techniques as well as a simulation model show that a good accuracy of travel times estimates can be obtained. Assuming that at least 5% of freeways travelers are equipped with a live cell phone(i.e. switched on), one can predict a 95% accuracy in freeway link travel time estimates. There is evidence that suggest that at least this proportion of vehicles in the Bay Area network will be equipped with live cellular telephones.

In summary, the research indicate that cellular positioning could well be a cost-effective means of making travel time measurements and conclude that a field test is needed to establish the feasibility of this approach. The field test will involve GPS to match the output of the cellular technique to the GPS output.

MOU 3015 – Field Operational Test of GPS and Cellular Technologies for Vehicle Probes

Y.B. Yim, PATH

The objective of this project was to conduct a field test of cellular technologies and the global positioning system (GPS) for vehicle probes. The Field Operational Test (FOT) intended to demonstrate two scenarios: 1) the Global Positioning System and 2) cellular technology for vehicle positioning system. These demonstration scenarios have a common goal, that is, to measure the accuracy and reliability of vehicle speed or travel time on the Bay Area freeway network.

The field test intended to deal with two sample populations, one from GPS generated data and the other one from US Wireless generated data. Differences in means or variance between the two samples are tested. The result of the experiment will tell us whether US Wireless data and Differential GPS have produced similar data within the confidence level of 95%.

To assess the effectiveness and adequacy of cellular and GPS technologies for incident detection and speed information, the current state of the technologies and commercially available GPS units were investigated. The GPS detects nodes in the roads and send IP events through a wireless modem containing information on the position and time of the vehicles to a centralized database. The GPS unit sends continuous amounts of data to a laptop computer where software takes in the information and determines if a node point has been passed. Differential GPS eliminates the inaccuracy inherent in the signals being sent to the GPS unit due to selective availability.

In June 2000, data were collected with a GPS, Differential GPS, and two analog cellular phones in major freeways and local arterials in Oakland, CA. The data on GPS and DGPS are being reduced to support statistical analysis. The study team is currently waiting for US Wireless to furnish their data to PATH so it can be analyzed. The final report will be completed by December 2000.

MOU 382 – Development of a Cost-Effective Surveillance System for District 4

Joy Dahlgren, PATH

This project had two components. The first was to assess the feasibility of using toll tag equipped vehicles as probes to estimate travel times in the Bay Area. The second was to create a methodology for making decisions regarding surveillance investments in the Bay

Area. Our research found that using toll tag equipped vehicles as probes would indeed be feasible in many parts of the Bay Area. Not only are they feasible, they generally cost less both in terms of capital and operating costs than many competing surveillance options such as loop detectors, microwave and video detection. The congested bridges in the area, where loop detectors are not feasible, are prime candidates for toll tag probe readers. Congested sites with poor loop detector coverage that are near a bridge are also good candidates for early deployment. Once implemented in such locations, the performance can be assessed and better estimates can be made of their performance in other locations.

A method has been developed for determining how to develop the most effective traffic surveillance investment program, given available resources. The complicated decision structure for deciding when and where to install traffic surveillance and what type to install is broken down into a series of steps: 1) identifying information needs, 2) determining which can be met by traffic surveillance, 3) setting criteria for and evaluating the benefits of surveillance in various locations, 4) identifying alternative surveillance methods and estimating their capabilities and costs, 5) comparing the ratios of their benefits to costs, 6) and finally matching cost effective investments with available funds.

3. Traffic Management Systems

It is a well known fact that it is very difficult to build or expand freeways because of land constraints, environmental and other issues. Therefore, it is vital to manage the existing transportation network as efficiently as possible. PATH has two projects to study the dynamics of traffic around bottlenecks especially near on- and off-ramps to have a clear understanding of why and how congestion occurs. After understanding the dynamics of congestion, research can be performed to manage the congestion to make the freeways more efficient. Adaptive ramp metering is a major focus in the PATH program that has potential to manage the flows to reduce congestion. Incidents on the freeway often cause a great disturbance to the traffic and cause congestion. Researching ways to improve the incident management process is invaluable. Reducing congestion through advanced transportation management may also mitigate accidents and increase safety. Research is underway to determine if certain traffic flow conditions increases the rate of accidents.

MOU 354 - Incident Management: Process Analysis and Improvement Randolph Hall, University of Southern California

Incidents—such as collisions, stalls and dropped loads—are known to be a major source of highway delay. The amount of delay occurring during an incident depends on three primary factors: 1) the nature of the incidents, 2) roadway conditions, and 3) execution of incident clearance. The focus of this project has been on incident clearance, with specific focus on the response time component of dispatch time and the contribution of dispatching policies to delay.

A fundamental question in dispatching incident crews is whether to send the closest vehicle that is currently available or to wait for another vehicle to become available that is even closer. Waiting for a closer vehicle is advantageous because service time is effectively reduced, adding to capacity and providing system stability at higher incident rates. But waiting for a vehicle to become available adds uncertainty, which contributes to expected traffic delay. As a consequence any reasonably robust strategy must provide for a hybridization of the two objectives, trading-off greater certainty in response time against stability at higher utilization levels.

The project has compared situations where clearance crews operate within individual non-overlapping beats, to situations where rolling beats are utilized, in which vehicles are not restricted to a particular area. Evaluations were performed as a function of interchange spacing, and time penalties for changing direction to reach the side of the highway where the incident is located.

The project also developed a new program for simulating highways under alternative dispatching strategies. INCISIM is a computer program that simulates the occurrence of highway incidents, the dispatching of emergency vehicles, and the traffic flow on the network. INCISIM can represent multiple types of emergency vehicles, include highway patrol cars, freeway service patrol trucks, tow trucks operating from fixed bases, highway maintenance vehicles, and fire trucks. Incidents are represented by type classifications (corresponding to computer-aided-dispatch codes) and profiles (defining duration and magnitude of incidents). Delay is calculated as a function of these variables, along with traffic flows and highway capacities. INCISIM produces a complete log of incidents that occurred during the simulation along with statistics on highway delays.

MOU 356 - Effects of Increased Capacity on Congestion

Joy Dahlgren, PATH

The reopening of the section of I-880 immediately east of the Bay Bridge 10 years after it was destroyed by the 1989 earthquake provided a unique opportunity to study the effects of a significant highway capacity expansion that was not undertaken in response to past or anticipated development. Its effects will be primarily the result of the capacity expansion, rather than new development. This project was designed to use this opportunity to help answer the question: Does increasing highway capacity increase demand so much that there is no lasting congestion relief for existing users? This is a topic of great interest to transportation policy makers, planners, and researchers.

A questionnaire was mailed to a sample of people who used this section of highway on June 18, 1999 asking asked about the origin and destination of their trip, the time of day, the purpose, and how or if current travelers would have made the same trip before the reconstruction. Almost 1000 responses were received. These responses will help answer the following questions:

What proportion of respondents would have departed at another time if the new I-80/I-880 connector had not been open?
What proportion would have carpooled?
What proportion would have made the trip via public transit? What proportion of these by BART, AC, and other?
What proportion would have gone to a different destination? What destinations would these have been?
What proportion would not have made the trip?
What proportion would consider taking a job further away from home?
What proportion would consider moving further from their job?

They will also explain how trip purpose, amount of time saved, frequency of use, departure time, and trip length affect travelers' responses to increased capacity.

Preliminary analysis indicates that the most common effect was a change in departure time, 40%. People traveling during the morning peak were more likely to change, those traveling in the afternoon peak less likely. This is likely because differences in departure times were greater during the morning peak period. Analysis of the factors that affect traveler response are currently underway.

MOU 3004 – Access Control Strategies to Manage Traffic Backups and Increase System Capacity

Carlos Daganzo, University of California, Berkeley

Empirical evidence gathered during the first year of our study strongly suggests that new "smart" traffic control approaches can be used to relieve recurrent congestion caused by diverge bottlenecks. We have developed theories that are consistent with the empirical evidence and can therefore be used to evaluate proposed control strategies.

The following list highlights the main empirical findings from our extensive study of the FSP database (freeway I-880 near Oakland.)

- (1) FIFO blockage: Even on wide freeways, an off-ramp queue can grow across all lanes and entrap through vehicles in a first-in-first-out(FIFO) system with similar speeds on all lanes and a well-defined kinematic wave (KW). This can hamper freeway flow much more than an on-ramp bottleneck. In this case the FIFO regime arose a little over 2 km upstream of the exit and reduced discharge flow approximately to an average of 1500 veh/hr per lane across all lanes.
- (2) Variable capacity: Under FIFO, the freeway discharge flow can change significantly when the percent of exiting vehicles changes. In this case, it increased to 5750 veh/hr after 30 min at 4520 veh/hr when the exit percentage declined from 29% to 24%.
- (3) Non-FIFO congested regimes: This is where queued lanes move at different speeds, and this can persist for a long time. Presumably, this happens because different

drivers prefer different lanes depending on their destination. In this case, multi-pipe queued regimes were detected immediately upstream and immediately downstream of the FIFO queue. Semi-congested traffic regimes, where some lanes are queued and others are not, also exist downstream of the FIFO queue.

MOU 3011 - Examining How ATMIS Can Increase Freeway Bottleneck Capacity

Mike Cassidy, University of California, Berkeley

This research addresses freeway bottlenecks; where and how they arise and in what way(s) Advanced Transportation Management and Information Systems (ATMIS) might be deployed to increase their capacities. The study relies solely upon empirical observations.

To date, three active freeway bottlenecks have been identified and are being carefully studied. These are:

Southbound Interstate 5 between mileposts 16.5 and 17.3
Northbound Interstate 5 between mileposts 18.6 and 18.8
Eastbound State Route 22 between mileposts 9.0 and 10.1

These locations were identified after painstaking review of all available freeway loop-detector data within the Orange County Testbed.

Much of the analyses thus far have focused on the segment of Southbound Interstate 5 between mileposts 16.5 and 17.3. A bottleneck with diminished capacity arose whenever queues from the off-ramp spilled over and occupied the segment's mandatory exit lane. This diagnosis came through the use of traffic data visually extracted from video tape, combined with observations made from a floating-car and visual analyses of vehicle counts and occupancies that were measured from loop detectors and plotted in special ways. It was further observed that the lengths of these exit queues were negatively correlated with the discharge flows in the freeway segment's adjacent lanes; i.e., longer exit queues from the over saturated off-ramp were accompanied by lower discharge rates for the non-exiting vehicles. In these instances, the explanation appears to be "rubber-necking" on the part of the non-exiting drivers. Notably, whenever the off-ramp queues were prevented from spilling-over to the exit lane (by changing the logic of a nearby traffic signal), much higher flows were sustained on the freeway segment, and a bottleneck did not arise there. These observations underscore the value of control strategies that enable diverging vehicles to exit a freeway unimpeded.

MOU 3007 - Development of Tools to Assess the Effects on Traffic Safety of Changes in Traffic Flow Conditions under ATMS Operations

Tom Golob, University of California, Irvine

This project is aimed at developing an evaluation tool based on identification of the salient relationships between accident rates and characteristics and traffic flow patterns.

The data for the underlying analyses involve one year of accidents on six major freeways in Orange County, combined with traffic flow conditions extracted from loop detectors, and highway records. Data processing is a daunting task, due to the size and complexity of the various databases. However, most of this processing was completed in the first year of the project.

The most recent year with complete accident and traffic flow data for Orange County is 1998. The appropriate accident data from the TASAS database were obtained from Caltrans Headquarters and processed without problem. Complete Orange County 30-second loop detector data for 1998 were finally obtained. These data were loaded into an Oracle database and scripts were written to extract loop data corresponding to each of the 9,341 accidents on six major Orange County freeways in 1998. For each accident, 45 minutes of traffic flow data were extracted for each of four loops, the closest two loops upstream of the accident and the closest two loops downstream of the accident.

Accurate accident times are required to distinguish pre-accident and post-accident traffic flow conditions, but the time of occurrence of each accident is not known with accuracy. The recorded times from police reports is typically rounded off to the nearest five (and in some cases, fifteen) minutes. An algorithm has been developed to refine the time of an accident using the Testbed probabilistic neural network incident detection algorithm and shock-wave theory applied to the merged traffic flow data.

A highway characteristic file was also prepared for merging with the combined accident/traffic flow data. This file contains complete highway geometrics for the roadway section in which the accident was located and for adjacent sections upstream and downstream of the accident section (so that lane drops, ramp entries, etc. can be tracked). The file is being merged with the accident and traffic flow data.

In order to test the analysis methodologies and become familiar with the data, an analysis of weaving section safety was conducted. Fifty-eight weaving sections were identified on five freeway routes in Orange County, classified into four design types. Analyses uncovered statistically significant relationships between accident rates and characteristics and weaving-section type. Documentation of these results is underway.

MOU 3013 - Development and Evaluation of Adaptive Ramp Metering

Michael Zhang, University of California, Davis

In this research we evaluate existing ramp metering algorithms and develop new ones that address specifically the queue-spill back problem. The emphasis is on practical applications, that is we pay more attention to ramp metering algorithms that can be employed in the field under the current operating environment. The evaluation is carried out in three stages—conceptual, simulation, and field tests.

To date we have completed the conceptual evaluation of more than a dozen ramp metering algorithms that are classified into three categories: isolated, coordinated, and

integral algorithms. The isolated algorithms are local control algorithms that include ALINEA and Minnesota DOT's Zone Control Algorithm. The coordinated algorithms are system-wide metering algorithms that are further divided into two groups—cooperative and competitive. Both types of coordinated control algorithms use a two-level structure—local plus global control. In the cooperative algorithms local metering rates are further adjusted based on global traffic information, while in the competitive algorithms two sets of metering rates (local + global) were determined and the smaller one is used. Integral ramp metering algorithms are the most sophisticated control algorithms. They typically have an objective that is directly linked to the dynamics, constraints, and controls of the metered system, and obtain the metering rates by optimizing the objective. Examples of integral algorithms include METALINE, BALL/FHWA and various linear programming or optimal control based metering algorithms.

In the conceptual evaluation of various metering algorithms, we came up with a set of evaluation criteria that include three major aspects:

- 1) Effectiveness: To what extent each ramp metering algorithm reduces freeway, ramp, and surface street congestion.
- 2) Robustness: How a ramp metering algorithm functions under uncertainties.
- 3) Ease of implementation: Easier to program and maintain, simple to operate.

According the aforementioned criteria, we ranked all the algorithms reviewed and selected a few for simulation testing in PARAMICS. They are:

1. Zone algorithm (Minnesota DOT, local)
2. ALINEA (local)
3. Helper algorithm (Colorado DOT, coordinated)
4. Bottleneck algorithm (Washington DOT, coordinate)
5. SWARM (coordinate)
6. METALINE (integrated)

Further work in this research include developing the ramp metering API in PARAMICS, design simulation experiments, and test the selected and newly developed metering algorithms in PARAMICS. After simulation testing, the most promising algorithms will be tested in the field.

4. Traveler Information Systems

ITS technologies and services promise to increase mobility and safety. Advanced Traveler Information Systems (ATIS) will assist in achieving these goals by informing the traveler of the travel conditions and alternatives. Another benefit of ATIS that is difficult to quantify is the peace of mind the traveler has knowing the situation, why there's a backup, when is the next bus coming.

Transportation information can be disseminated in various forms to various user groups. Traffic information can be disseminated via changeable message signs around special events to balance traffic flows to and from the special event. Traffic information can be disseminated to commercial vehicle operations (CVO) to assist them in dispatch or route their vehicle more efficiently. And finally, transportation information can be disseminated via the telephone or internet to travelers so they can make wise decision on how, when, and where they should travel. The PATH research program in the last year has investigated these different applications of ATIS and the research is described below.

MOU 348 – Event-based ATIS: Practical Implementation and Evaluation of Optimized Strategies

R. Jayakrishnan, University of California, Irvine

Advanced Traveler Information Systems (ATIS) is an area of research and technology aimed at improving traffic conditions by helping travelers use existing transportation facilities more efficiently. Many implementations of ATIS include changeable message signs (CMS), which can be used to offer travelers alternate routes through congested regions of the transportation network. This study primarily investigated the real-world application of CMS during special events in Anaheim and whether drivers make use of the CMS facilities.

This research project has developed a comprehensive ATIS evaluation framework. This framework is utilized in setting up optimized routing strategies and generating messages for the CMS. This study incorporated driver compliance behavior into the simulation of the system, that is, whether drivers take advantage of CMS and suggested alternate routes.

A set of new CMS messages were tested and evaluated off-line in a simulation and then implemented in the real world during several sporting events in Anaheim. According to the traffic data, it was witnessed that the new CMS messages induced changes in the traffic pattern around the event. Rough estimates of the compliance rate to the CMS were 13%, which is not high but enough to improve the traffic condition. The field tests showed that CMS routing can be a useful tool for event traffic management.

MOU 363 – Consumer Research on ATIS Technologies

Y.B. Yim, PATH

The purpose of this project was to conduct two studies related to the TravInfo Evaluation project; 1) the second phase of the Broad Area survey and 2) the second phase of the Traveler Advisory Telephone System (TATS).

Two papers are being prepared for the Broad Area surveys. Both papers consisted of modeling travel behavior with traveler information. The extent to which the Bay Area

travelers are willing to pay for traveler information was investigated. Modal, route, and information choice models were calibrated using logit, probit, and factor analysis tools. Two types of travelers were identified; people who are highly receptive to information disseminated via advanced electronic media and those who are more likely to rely on conventional media (radio, TV).

A draft paper for the traveler advisory telephone system is being prepared and the final paper will be completed by December 2000. The study found that people who call TravInfo are freeway users and in upper and middle-income groups. This finding is similar to the first wave of the TATS caller survey.

MOU 364 – Financing Plan for Public Supported ATIS

Y.B. Yim, PATH

This project is an institutional analysis about alternative approaches to sustaining publicly supported ATIS. There are several reasons for considering this subject: 1) many of the original federally supported Field Operational Tests (FOTs) and other deployment initiatives have completed their demonstration phases and there is uncertainty about the availability of continued federal support for deployment; 2) there is increasing interest in privatizing various ATIS functions and therefore relying more on private sector investment and revenue generation from the sale of products and devices; 3) desire to recover costs of data collection, processing and dissemination through fees or barter arrangements; 4) there is varied experience (U.S. and abroad) to draw upon in defining these alternatives.

The principal objectives of the project were to:

1. Investigate alternative revenue approaches to achieve a self sustaining ATIS
The emphasis is on revenue approaches that minimize public funding. Identify institutional barriers to achieving self-sustainability. The intent is to identify those institutional and legal barriers that constrain the effectiveness of public-private partnerships, inhibit ATIS market growth, and preclude full participation of the public and private sectors.
2. Framework of assumptions
The analysis takes place within the context of a set of assumptions about the role of the public and private sectors in transportation management and traveler information, with these implications: 1) the public sector is expected to pay for the cost of ATIS to the degree it contributes to public sector goals; 2) public support requires dissemination of “core information” on an equitable basis; 3) “core information” enhanced by ISPs can generate a revenue stream for profit; and 4) each partnership needs to determine the line between public and private interests.

Over two dozen private and public sector representatives were interviewed and a draft report on the finding of the interviews are being documented. The final report will be prepared by December 2000.

MOU 365 – TravInfo Evaluation, TIC Study

Mark Miller, PATH

This project's objective has been to understand how a private and for profit company can operate a transportation information center, in this case, the TravInfo Traveler Information Center, that would normally and customarily be operated by a public sector organization. This research offers a unique opportunity in the context of the TravInfo Field Operational Test whereby a private sector organization is operating TravInfo's Traveler Information Center. The primary goals of this project are to gain an understanding of the human element of TIC operations, and the degree of success to which a member of the private business sector can operate a transportation information and management center relative to its operation by a public sector organization.

The primary accomplishment has been the completion of the synthesis and integration of all TravInfo evaluation project components into a single cohesive document: The TravInfo Evaluation Final Report. Relative to this project, this includes the operational effectiveness of the traveler information center (operator interface, physical working environment, and operator response times), system reliability, and institutional analysis aspects.

MOU 3003 - ATIS for Ground to Air Connectivity

Randy Hall, University of Southern California

Overnight parcel networks require a high level of reliability in all service legs to meet their delivery commitments. Delays in any portion of the trip can either cause a missed connection (and failure to meet commitment), or result in excess costs for expediting shipments. Perhaps the most critical leg in the journey is shuttling shipments from local terminals/stations to air terminals. These shipments typically occur during the evening rush, making them especially susceptible to delays. The project will be a collaborative effort with United Parcel Service and Caltrans to evaluate information services targeted at assisting overnight carriers in routing their trucks, scheduling their shipments and optimizing their departure times.

The project was in a preliminary phase in the 99/00 year, focused on data gathering and initial analysis. Both Federal Express and United Parcel Service have been active participants, providing data on truck movements between their local terminals and LAX and Burbank airports. These data will help develop a model for predicting travel time as a function of traffic conditions. We have also developed a dispatching model for predicting the consequences of delayed shipments, in terms of their impacts on airport sorting operations and aircraft departure.

5. Public Transportation Systems

To address the transportation needs of today and the future, California needs creative and innovative solutions that provide alternatives to reduce traffic congestion, promote equity and flexible travel, cut air pollution, and link customers to public transportation. The PATH vision integrates technologies and alternative transit strategies with conventional transit service to improve mobility and reduce congestion.

PATH is testing and evaluating alternative transit systems including traditional transit services, car sharing, and demand responsive transit. Examples of PATH's work include: 1) car sharing pilot tests demonstrating advanced technologies and exploring alternative business models, system viability, and market demand, 2) ITS impact and consumer research for a demand responsive transit system, 3) assessment of California's passenger intermodal operations. This research is described below.

MOU 380 - CarLink I Evaluation

Susan Shaheen, PATH

Carsharing is the use of a fleet of vehicles by a group of individuals to assist in meeting their transportation needs. Smart carsharing employs electronic and wireless technology to organize, track, collect data, and provide vehicle availability information to users. Through carsharing, many people have access to, and drive a set of shared vehicles.

While carsharing is a relatively new concept in the U.S., it is more widespread in Europe. Research is needed to evaluate several carsharing models to determine how to adapt, design, and implement such programs in U.S. markets. CarLink is one model that accomplishes this goal. CarLink integrates short-term rental vehicles and smart communication and reservation technologies to facilitate shared-vehicle access at transit stations or other activity locations. CarLink incorporates the convenience of a private automobile with the environmental and societal benefits of transit.

The CarLink I field test was a ten-month pilot program designed to investigate carsharing use and behavior primarily in the eastern portion of the San Francisco Bay Area. Launched on January 20, 1999, the CarLink field test was an example of a "smart" carsharing system designed to meet the unique travel patterns of this region. It incorporated traditional and reverse commute travel patterns and a day-use fleet application, tested at an employment center.

The 54 individuals enrolled in the CarLink project shared 12 natural gas –powered Honda Civics for 10 months. The cars were based in premium parking spaces at the Dublin-Pleasanton BART station. "Homeside Users" drove a CarLink vehicle between their homes and the BART station daily, keeping the car overnight and on weekends for

personal use. "Workside Commuters" rode on BART to the Dublin-Pleasanton station and then drove CarLink vehicles to and from work at Lawrence Livermore National Laboratory, 15 miles away.

Key study findings include:

- 1) CarLink users' commutes were less stressful.
- 2) CarLink participants drove less than before they joined the study.
- 3) CarLink participants increased their use of BART for recreational travel.
- 4) The combination of CarLink, BART and carpooling resulted in a net commute reduction of approximately 20 vehicle miles (on average) per day.
- 5) CarLink resulted in at least 20 new BART trips each day.

Several Homeside Users said that if CarLink became a permanent service, they would sell one of their personal cars, which would greatly reduce their transportation costs.

MOU 3009 – Expanded, Year-Two CarLink II Pilot: A User, Economic, and Institutional Evaluation of Smart Carsharing

Susan Shaheen - PATH

The PATH research team, building upon CarLink I, will evaluate the success of the CarLink II pilot project, with 27 Honda Civic vehicles, and determine its ability/potential to transfer viable smart technologies and business models to other locations. This study takes place on three levels: 1) technology development, testing, and evaluation; 2) business model development, testing, and analysis; and 3) user benefit evaluation.

I. Carsharing Technology Development, Testing, and Evaluation

PATH researchers conducted a technology assessment, which included expert interviews and an extensive web search of fleet management and reservations systems, navigational-based services, and existing carsharing technologies (e.g., Mobility, LisElec, INVERS, and Teletrac). Several potential vendors were identified to respond to a University of California, Davis (UCD) CarLink technology request for proposal (to be issued Summer 2000). The purpose of this task was to determine whether or not there were companies that would be interested in developing CarLink II technology. It was determined that at least one to two companies would respond.

II. Market Case Studies

For this research step, PATH researchers conducted an evaluation/forecast of the potential market for shared-use vehicle fleets in the U.S. along with a major original equipment manufacturer (OEM). This study served as an exploratory analysis of broader markets for carsharing (i.e., beyond the CarLink commuter-based model). Researchers investigated government fleets, the rental car market, resorts, universities, and gated

communities. All of these markets were identified as having shared-use market niche potential.

III. CarLink II Technology Development Project

Researchers have begun joint collaboration with Dr. Raja Sengupta and Aaron Steinfeld (PATH), working on a Caltrans funded MOU, to provide CarLink users with: 1) access to transit schedules and 2) a communications device for coordinating carpools with other CarLink members via a cell phone or personal digital assistant (PDA).

IV. UC Davis CarLink II Feasibility Support

PATH researchers provided input and reviewed CarLink II site selection documents, which included traffic data, origin-destination patterns, and transit station analysis. These data were collected and analyzed to support the project partners selection of the best location for CarLink II.

V. Business Model Development, Testing, and Evaluation

As part of this task, PATH researchers are developing a spreadsheet for documenting and calculating CarLink costs and revenues, given different market conditions (e.g., high willingness to pay, high volumes, subsidies, etc.). Furthermore, PATH researchers are working with UCD staff to calculate comparison data on existing shuttle services in the Bay Area (e.g., availability, ridership levels, frequency of service, cost, and subsidies).

MOU 375 – Assessing Opportunities for ITS in California’s Passenger Intermodal Operations and Services

Mark Miller, PATH

This project’s objective is to recommend strategies for the improvement of passenger intermodal operations and services by both evaluating the current state of passenger intermodalism in California and by identifying ways that intelligent transportation systems can be used to enhance the services currently in place from both the user and institutional perspectives. A three-tiered approach was developed to conduct this evaluation. First, site visits to passenger intermodal sites in urban areas of California were conducted. Second, an institutional survey has been developed and will be used to assess the institutional perspective of transit properties from a sample of the visited intermodal sites. Finally, a user survey has been designed and administered at one of the sites for which the institutional interviews will be conducted. This three-tiered approach should help provide a nearly complete and clear picture of the current passenger intermodal system and all its major players in California.

The site visits have been made and documented in a report that was an interim deliverable for this project: “A Field Survey of Site Visits to Passenger Intermodal Transfer Facilities in California”, PATH Technical Note 2000-1. A total of thirteen site

visits were made at passenger intermodal transfer facilities in the San Francisco Bay Area, metropolitan San Diego, and the Sacramento Area. Each site visit considered four stages of the passenger intermodal transfer experience: approach to the facility, the ticketing process, the transfer within the facility and departure from the facility. Comparisons and contrasts were made across regions and modes leading to the formation of generalized hypotheses regarding intermodalism that will be tested later in the institutional survey portion of the project. The information gathered in the site visits was intended to provide a better sense of the current state of intermodalism in urban areas of California and in so doing gain a better sense of the systems in place to better identify areas for improvements. Certainly however, the data obtained from the site visits is rather anecdotal in nature and is not meant for drawing any firm conclusions.

As part of the final analysis, interviews will be conducted with transit properties serving a selection of these sites, and a user survey at one of these sites has already been conducted. The site visits gave us a better idea of the areas of focus for other parts of the project. With the interviews and field survey, we will gain more insight into our initial hypotheses about intermodalism. Further, these surveys will help us identify additional ways in which intelligent transportation systems technologies can be used to further promote passenger intermodalism in California.

MOU 340 - San Gabriel Valley Smart Shuttle Technology Field Operational Test Evaluation

Genevieve Giuliano & James Moore, University of Southern California

This project is the evaluation of the San Gabriel Valley Smart Shuttle Technology (SGVSS) Field Operational Test (FOT). Results are drawn from a comprehensive evaluation of the FOT conducted over a three year period. The SGVSS attempted to integrate services of three local municipal public transit operators and a regional fixed route operator via networked computer-assisted dispatching, automated vehicle location, and mobile data terminals.

The SGVSS Field Operational Test was scheduled to end in December of 1999. Because of extensive and ongoing problems with the software and hardware, deployment of the system was repeatedly delayed. As it turned out, the SGVSS system was never fully deployed. Duarte and Foothill elected not to keep the SGVSS system; only Monrovia retained the dispatching hardware and software.

The purpose of an FOT is to determine whether the given technology application is appropriate for large scale deployment. Inherent in the test is a consideration of institutional context. There is no such thing as an FOT failure; there is much to be learned from tests that did not work as anticipated. While this FOT did not accomplish system integration, it provides many useful lessons for future advanced technology applications.

1. Goals and objectives should be clear, appropriate, understood by all parties, and agreed upon by all parties, especially those charged with carrying out the FOT. In this case

the goal of “integrated system” became “integrated technical system.” Such a system served no useful purpose for the participants. Participants tried to use the system to address their own service objectives. True integration would have required cooperative efforts among the participants, strong leadership, and enough time to achieve consensus agreements.

2. Institutional arrangements should be formal, clearly specified, and should allocate responsibility and risk appropriately. In SGVSS there were formal contracts for the various key consultants, but product delivery could not be enforced. The lead consultant had responsibility for delivery, but had no effective means for demanding subcontractor performance. There were no formal agreements for the project participants. It was therefore possible for them to drop in and out of the project and change decisions on key matters as the FOT progressed.
3. Any FOT should pass a basic test of reasonableness before it is allowed to go forward. A commitment to the project on the part of participants, and a market for the product should be demonstrated as necessary conditions. Had SCAG investigated the services within the three cities, it would have been obvious that there was no real market for integration.
4. The technology should fit with the problem being solved. The SGVSS technical system was far more sophisticated and complicated than required for sharing basic operating information or even accommodating transfers. Technical complexity contributed to the software problems and the associated delays.
5. Delays are inevitable in FOTs and should be built into the schedule. The tight schedule added to the difficulties of SGVSS by driving decisions that ended up generating more delays and ultimately the failure to produce a functioning integrated system.
6. New technology tests should be as simple and incremental as possible. The difficulties of developing even incrementally new applications are generally underestimated. Public transit is a highly complex operation. Each service is in some way unique and unpredictable humans are involved, both as consumers and as service providers. SGVSS turned out to be a bundle of numerous different applications, greatly adding to its complexity.
7. Basic technical knowledge and computer literacy of participants cannot be assumed. Technical knowledge is important for two reasons. First, participants with limited technical knowledge cannot effectively communicate with highly technical consultants, yet such communication is essential if the technology deployed is to do the job the participants want. Second, interacting with computers and other technologies is intimidating for those with little technical background. At Monrovia, some dispatchers and drivers simply could not work effectively with the new system. And training took many times longer than anticipated, because these workers were so unfamiliar with computer technology.

MOU 398 – Demand Responsive Transit Service Consumer Research

Y.B. Yim, PATH

The purpose of the study was to conduct consumer research on personalized demand-responsive transit service (PDRT). As evidenced in most demonstration projects, a demand-responsive transit service was not cost-effective. Two factors contributed to the failure of these demo projects. From the operator perspective, either the design concept had flaws or the computer technology wasn't available to efficiently operate the system. From the user perspective, the operators did not consider the needs of the users. Most of these systems provided the services without asking what type of demand-responsive service would attract consumers. While recognizing the importance of operating system efficiency, advanced routing algorithms or computing technologies may not necessarily generate increased ridership.

The study objectives are:

- 1) To elicit desired features of a personalized transit service, i.e., real-time information, the content of information, acceptable waiting time and number of stops, and required travel-time.
- 2) To assess the travel characteristics and profiles of potential users in terms of socio-economic variables.
- 3) To identify the geographical distribution of potential riders in the Bay Area.

Consumer research on the PDRT system was conducted through focus group meetings and telephone interviews with Bay Area households. The results of six focus groups and the survey indicate that the idea of a personalized transit service may appeal to commuters as well as non-commuters. There is significant potential to attract travelers to PDRT; about 15% (N=1000) of those surveyed reported that they were “very likely” to use the PDRT service and another 47.7% (N=1000) were willing to consider PDRT as an option. A majority of these PDRT predisposed were willing to pay between \$5-\$10 for a 30 minute trip using fixed-schedule service (62%; N=627) and on-demand service (73.0%; N=642). A majority of the PDRT predisposed were also willing to use the service despite an average 20-minute wait time for pickup and 54.5% were willing to take PDRT despite it taking 15 to 20 minutes longer than their current commute or most frequent trip.

Responses to attitudinal questions revealed a strong (positive) preference for flexibility in scheduling pick-up times, conducting criminal/driving background checks on all van drivers and being dropped off at the front door after dark (for safety reasons). The results show that a reasonably priced PDRT service that is reliable and meets customer expectations (of cost, travel time and wait time) can be successful. Respondents were quite realistic in their expectations about the PDRT service attributes, especially the longer travel times and wait times involved in using PDRT.

MOU 3002 - Evaluating the Impact of ITS on Personalized Public Transit
Maged Dessouky – University of Southern California

The passage of the American with Disabilities Act (ADA) has created renewed interest in Demand Responsive Transit Services. At the same time, the introduction of Intelligent Transportation Systems (ITS) such as dispatching and scheduling software, automatic vehicle location (AVL) devices, mobile data transfer (MDT), etc. has made such systems less complex to operate because of the automatic processing of information. This advancement in technology, which is recognized by transit providers, has caused many vendors to develop specialized software and other equipment to support management of paratransit and demand responsive service. The objective of this research is to investigate the use of ITS technologies to improve the service efficiency of DRT providers and to evaluate the different opportunities it creates to improve the overall performance of DRT systems.

We reviewed different technologies that have been implemented or are being considered for implementation by the transit providers. Technologies that have been implemented include AVL, advanced wireless communication, MDT, computerized vehicle navigation, and geographic database. Emerging technologies that have potential for implementation include internet dispatching, superphones, personal data assistant's, and smartmaps.

It is anticipated that the responsiveness and costs of demand responsive transit may be improved by utilizing these ITS technologies. For example, real-time control and decision-making technologies may be applied to improve the quality of transit service and to facilitate intermodality. In most cases specialized software can facilitate this task. As part of the research efforts, we conducted a review of the commercial software in order to record their functionality. We identified twenty vendors who distribute potential commercial software that supports the paratransit industry. Of these vendors, three firms completed the survey that we administered. The other firms stated that they did not believe their software package was suitable for this industry. Our review shows that most of the software has the capabilities to automate reservation, scheduling, billing and maintenance. The intent of this review was not to make a recommendation of any particular software. The purpose was to list the features of the available software and to identify if they have capabilities to support real-time scheduling and reservation of DRT service within the paratransit industry. We note that this industry is changing very rapidly due to changes in the marketplace. There has been numerous merges leading to decreasing number of software packages specifically addressing the paratransit market while their capabilities are continuously increasing. Most of the packages have built in interfaces to accommodate AVL, global positioning systems (GPS), and MDT.

In order to document how public agencies are adopting the software and technology, we conducted an in-depth phone interview with OUTREACH, Inc. who is the paratransit provider for the Santa Clara Valley Transportation Authority. Also, we conducted a site visit at Antelope Valley Transit Authority. We met with representatives of the agency as well as the contractor that provides paratransit service for the region, Laidlaw. Antelope Valley was selected based on suggestions from Access Services personnel who felt that

this region was where it might be beneficial to use a hybrid fixed route and curb-to-curb system. The travel distances in Antelope Valley are large enough to justify a transfer point between the two different types of transit services. Furthermore, most of the disabled and elderly passengers travel to a central location where most of the hospitals are located. Finally, AVTA is a small to mid-size agency so that there is opportunity for effective communication between their fixed route and paratransit services. AVTA provided data of their operations including pickup time, travel distances, fleet size, etc. This data was used to form statistical distributions of representative paratransit operations.

In the next phase of the research, we will concentrate on developing alternative system designs as well as an analytical model. In particular, we will compare a strictly curb-to-curb system with a hybrid curb-to-curb and fixed route system. The alternative configurations will be tested using the AVTA data.

6. Decision Support

Planners and engineers working in the field of ITS are often challenged by the decision makers to show how ITS can enhance the benefits of projects by using existing facilities more efficiently. How do we show the benefit-cost of ITS projects? Existing benefit-cost models in use by Caltrans and others do not address the unique benefits of ITS such as providing more information to highway and transit travelers to assist in their route and mode choices. Are there other benefits that can be derived from ITS deployment such as reduced emissions? Transportation professionals and decision makers also need methods for evaluating the performance of the transportation system to determine how to improve operations.

ITS transportation professionals are facing a difficult task in assessing benefits and costs associated with ITS projects and measuring system performance. In many cases such information is simply not available because the technologies have not been implemented yet. Or such projects may not have been in operation long enough to have historical data collected. In a financially constrained environment, information on this type of information on ITS projects is vitally important for planning and implementing ITS programs and setting priorities for future ITS deployments.

The Caltrans New Technology and Research Program and PATH have undertaken a long-term research program to develop a model capable of evaluating the benefits of ITS. Research projects under this program area include, in addition to the benefit-cost models, development of a freeway performance measurement system model and development of a method for measuring the air quality benefits of ITS deployment. Finally, the research findings regarding benefit-cost and the models developed must be disseminated to transportation professionals. One way this is accomplished is through the ITS Evaluation Website project which makes the decision support research available to others. This research is described below.

MOU 3001 - Evaluation Methods for Measuring the Value of ITS Services and Benefits from Implementation

David Gillen, University of California, Berkeley

This project encompasses the knowledge base established in the undertaking and completion of MOU 357 and the publication of *Operations Manual for Decision Analysis in Assessing the Economic Value of ITS Projects*. This publication provides a framework and starting point to undertake the evaluation of the implementation of ITS projects. What distinguishes the work undertaken under MOU 3001 is that not only are individual technologies evaluated as an after-the-fact implementation of ITS but the process of the application is also evaluated.

MOU 3001 has and will undertake specific evaluations in two different areas of ITS application: (1) public transportation operations with specific consideration of AVL applications and (2) freeway service patrol and emergency management. These applications will be conducted after achieving a greater understanding of the productivity benefits of ITS and the existence and option value benefits of ITS respectively.

In the past year, four research projects were completed. First, as part of a traffic operations assignment to assess ITS applications and their potential for net benefits we examined a number of individual ITS applications and explored the synergies that might arise when they are implemented together. We found that shifting technologies from pre-programmed ramp meters to linked systems had a significant impact on the benefits received from implementation of multiple applications of ramp meters. Second, we found that linking ATMIS with ramp meters had a perceptible increase in benefits above those that were obtained from individual applications of these projects. The results are contained in report *Caltrans Tops Evaluation: Assessing The Net Benefits Of Its Applications*.

In a second research project we explored the productivity and cost efficiency affects of ITS applications in public transit. Our investigation focused on AVL applications. Using a total factor productivity model (TFP) we developed measures for 26 different transit system in the US with data ranging over the period 1988 through 1998. AVL was implemented by a number of these firms at different points in the data period. A statistical analysis of the differences in TFP among firms showed those with AVL had a significant increase in productivity. In other parts of the research we explored the underlying drivers of this productivity differences. The results are available in research report *Productivity Benefits and Cost Efficiencies from ITS Applications to Public Transit: The Evaluation of AVL*.

The third research project undertook to determine whether and how ITS affected the economic growth and productivity of the California economy. A major objective of ITS is to enhance the welfare of California. This research provides some evidence on how and whether ITS applications affect the productivity. Our research shows that based on

county data that ITS applications explain a small but statistically significant difference in productivity between counties in California. This research is reported in research report *Measuring the Aggregate Productivity Benefits from ITS Applications: The California Experience*

Our fourth research report provides an analysis of incident management programs which are one of the key elements of Intelligent Transportation Systems (ITS). The goal of such programs is to clear the incidents on the roadways and return traffic flow on the roadway back to normal as soon as possible. Incident management programs have been introduced in many places to help reduce incident detection and duration time. They make use of ITS services and coordinate among the various operating agencies to meet the goals of reduction in the detection and clearance of incidents. Highway assistance services, also called the freeway service patrols (FSP), are one of the main approaches used by incident management programs. These patrols use vehicles to patrol the heavily traveled segments and congested sections of the freeways that are prone to incidents. This research is reported in *Evaluation Methods For Measuring The Value Of Its Services And Benefits From Implementation: Part X Freeway Service Patrols*.

MOU 3012 – Freeway Performance Measurement System, Phase II

Pravin Varaiya – University of California, Berkeley

Caltrans needs a freeway performance measurement system that extracts information from real time and historical data. PeMS is such a system. It presents information in various forms to assist managers, traffic engineers, planners, freeway users, value added resellers (VARs), and researchers.

PeMS obtains 30-second loop detector data in real time. Caltrans is divided into 12 districts; together they generate 2 GB of data each day. District 7, Los Angeles, accounts for 1 GB. The PeMS database currently has 400 GB of data online. PeMS is a low-cost system. It uses commercial-of-the-shelf products for communication and computation. Detector data are retrieved over the Caltrans ATM wide area network to which all districts are connected. The 45 Mbps link connecting PeMS to this network costs \$2000/month. The PeMS computer is a four-processor SUN 450 workstation with 1GB of RAM and 1 terabyte of disk. It uses a standard Oracle database for storage and retrieval.

The PeMS software architecture is modular and open. A new district can be added online with six person-weeks of effort, with no disruption of the district's TMC (Traffic Management Center). Data from new loops can be incorporated as they are deployed. New applications are added as need arises. PeMS has been in stable operation for 18 months.

PeMS is easy to use; built-in applications are accessed through a Web browser. Custom applications can work directly with the database. Caltrans managers can instantaneously obtain a uniform, and comprehensive assessment of the performance of their freeways. Traffic engineers can base their operational decisions on knowledge of the current state

of the freeway network. Planners can determine whether congestion bottlenecks can be alleviated by improving operations or by minor capital improvements. Traffic control equipment (ramp-metering and changeable message signs) can be optimally placed and evaluated. Travelers can obtain the current shortest route and travel time estimates. PeMS can serve to guide and assess ITS deployment.

MOU 355 - ITS Evaluation Website

Joy Dahlgren, PATH

This was a year of maturing, redesign, and redirection. The site went on-line in July 1996, and by the end of 1999 contained material on all the major ITS user services. It needed updated presentation of the material, updating of some of the older content, and substantial on-going maintenance to keep it well organized and attractive to users

The original content of the site attempted to give people an overview of ITS, provide objective information in significant detail about the various ITS services, and provide references for people who wanted to explore these services in more detail. The objective has not changed. But because of the volume of information contained in the site, updating this detailed information could absorb all of the available resources. Therefore, a new approach has been taken. Each ITS service will have a 1- or 2-page “At-a-glance” summary that will briefly describe the service, where it has been implemented, and key findings. This will be updated regularly and will link to the original, more detailed report on the service as well as more recent papers and reports on the service.

To remain useful, the website must reflect the most recent information about ITS. Therefore, a significant portion of the webmaster’s time is devoted to reviewing current ITS literature, websites, and newsgroups, searching out good ITS reports, papers, and articles to publish on the site. This sometimes involves obtaining permission to publish them—the ITS website may be the only place that magazine articles are available on-line.

The site now contains the on-line library, a decision-support section, a section on benefit-cost analysis and spreadsheets for performing such analysis, a glossary, information on the ITS architecture, information on ITS training, and links to other ITS related websites. The content is indexed both by ITS user service, as defined in the ITS architecture, and by topic area in general usage. Users can see both indexes. A search engine has just been added to the site so users can search by key word without looking at either index. Material that relates to more than one user service, such as traffic surveillance, is linked to all relevant user services.

The name of the site was changed from *LEAP*, to the more descriptive *ITS Decision*. The page format has been redesigned and the home page now includes new graphics, new indexes, a featured new addition to the site, and information on new additions. More graphics have been added to the site (these were avoided initially because they took too much time to load).

The major web search engines have been contacted to let them know about *ITS Decision*. A new brochure was produced and distributed at the ITS America annual meeting, at PATH meetings, at the UC Transportation Library, at other meetings, and by Caltrans New Technology and Research Program. Usage statistics show that the number of users increased from 1100 in February to 1600 in April through June. These users request about 8000 pages per month.

Use statistics show that 68% of topic requests are for traffic management and electronic payment, the oldest subjects on the site. Updating these will be the highest priority for graduate transportation students working on the site. The webmaster and project manager will continue to scan the literature and web for new material to add to the site. Slightly less than half of the hits are for resources, particularly the on-line library and decision support. The addition of an expert system to guide users toward services that would suit their needs and a case-based reasoning system to help them evaluate the effectiveness of implementing these services in their situation has been proposed.

***MOU 381 – Integrating a Comprehensive Modal Emission Model into ATMIS
Transportation Modeling Framework***

Matthew Barth, UC Riverside

In order to estimate the potential safety, congestion, and air quality improvements of intelligent transportation systems, new and improved analytical techniques and simulation models are being developed. In terms of environmental effects, the University of California-Riverside, College of Engineering-Center for Environmental Research and Technology (CE-CERT) has recently completed a four-year NCHRP project to develop a comprehensive modal emissions and energy consumption (CME/EC) model that can be directly used for ITS evaluation. In a parallel PATH project (MOU #381), CE-CERT has examined the key interface issues between the detailed CME/EC model and other ITS simulation models and analytical techniques developed within the PATH program. Methodologies for integrating various ITS transportation models/data sets with the CME/EC model has been studied. These integration issues are not trivial; many ITS simulation models and analytical techniques inherently have different levels of aggregation and detail (e.g., both in time and across various vehicle fleets). The CME/EC model was originally designed to operate with microscopic transportation models (i.e., every vehicle modeled second-by-second); however, it is currently being adapted to work with both mesoscopic and macroscopic transportation models as well.

There are several PATH projects that are improving upon existing simulation models and analytical techniques used to evaluate ATMIS. Many of these projects are based around the Paramics model, so much emphasis was put into developing an Application Program Interface (API) emissions module that works directly with Paramics. This API has been completed and has recently been tested in a Paramics-based evaluation project. This evaluation project focused on the congestion and air quality problems associated with the I-215/SR-60 corridor in Riverside County. This is a corridor that has wide variations in vehicle fleet mix and significant road grade that affect traffic flow. The corridor has been

modeled for current and future scenarios using Paramics and the newly developed emissions module. The traffic flow and emission results are currently being analyzed and documented in the final report.

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