The Impact of Intelligent Transportation Systems (ITS) on Vehicle Emissions

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Intelligent Transportation Systems (ITS) have generated considerable enthusiasm in the transportation community as potential methods of improving highway safety, reducing highway congestion, enhancing the mobility of people and goods, and promoting the transportation system’s economic productivity. But the effect ITS will have on air quality, specifically, vehicle emissions, is uncertain. Two factors will be most influential:

- Vehicle emissions can be reduced by implementing several ITS technological bundles. Advanced Vehicle Control Systems (AVCS) implemented at the vehicle level will safely smooth the traffic flow, minimizing the stop-and-go effect that leads to higher emissions. Advanced Traffic Management/Information Systems (ATMIS) will minimize congestion and subsequently emissions: for example, by allowing dynamic re-routing to take place on the roadway network, and by aiding in trip-chaining practices.

- However, the implementation of ITS technologies may induce additional traffic demand that leads to an increase of total vehicle miles traveled (VMT) by making the transportation system more desirable. If ITS allows smoother flow and higher speeds on the roadways, people may choose to live farther away from work, since they could commute from farther away in less time.

Researchers at UC Riverside’s College of Engineering—Center for Environmental Research and Technology (CE-CERT) have been evaluating the direct impact of ITS traffic operation on vehicle emissions. Reasonable assessments can be made as to the direct impact of ITS on air quality by using appropriate measurement and modeling techniques. The research thus far has been focused on actual implementations of proposed ITS strategies, and does not consider the effect of potential induced traffic demand.

In order to determine the direct impact of ITS technologies on air quality, significant improvements must be made in traffic simulation and travel demand models by closely integrating vehicle emission models. Since existing traffic, emissions, and planning models have been developed independently of each other, they are difficult to integrate together. Current emission models (i.e., MOBILE and EMFAC, developed by the US Environmental Protection Agency and the California Air Resources Board, respectively) functionally relate emissions to average vehicle speed and density, and are not appropriate for analyzing ITS scenarios. Under ITS conditions, the dynamic behavior of vehicles will be very different compared to today’s traffic conditions, which current emissions models are based on. Modal emissions data (emissions data associ...
PATH and the National ITS Architecture Program

Mark Hickman
PATH

Recently, the US Department of Transportation (DOT) undertook an ambitious program to define and develop a national intelligent transportation system (ITS) architecture. A program bulletin describes the architecture as a "framework that describes how system components interact and work together to achieve total system goals. It describes the system operation, what each component of the system does, and what information is exchanged among the components." [1] Without a doubt, the development program will have a significant impact on the way intelligent transportation systems are planned and implemented well into the next century. A national ITS architecture will be used to develop national communications and interface standards for ITS, as well as to provide common data, information, and functional descriptions for the design and implementation of ITS products and services.

Researchers with the California PATH program have been working hard on the program for the past 15 months. Below, we outline the major elements of the national ITS architecture development and point out some of the significant areas where PATH has contributed to this effort.

Program Overview

One of the primary goals of the architecture is to provide national interoperability of certain ITS components and communications technologies. This may be done through nationwide standards on certain communication interfaces and through direct federal policies to direct or permit the associated technologies. At the same time, the architecture must also be flexible and open to permit the maximum level of public and private sector participation in developing and marketing ITS products and services.

The architecture is intended to support a broad range of user services envisioned under ITS Phase II. These services include those more traditionally grouped in the areas of traffic management, traveler information, public transportation, emergency management, commercial vehicle operations, and vehicle safety systems (including vehicle control). The architecture provides a common set of functions and data flows to perform these required user services, and specifies where these services and data flows are to be accommodated (e.g., in a vehicle or at the roadside). In this way, the architecture provides a framework to guide the development of communications and other interface standards to support ITS-related functions.

DOT originally sponsored four competing teams in a two-phase project as they sought to define this national systems architecture. Phase I, which began in September 1993, is nearing its conclusion. We are now (December 1994) in a time of evaluation and selection of which teams (out of the original four) will proceed to the more detailed architecture definitions in Phase II. Phase II will begin in February 1995 with the goal of defining a single national ITS architecture by July 1996.

PATH Participation

California PATH played a significant role in Phase I as part of the architecture development team headed by Rockwell International, with additional team members from GTRI, Apogee Research, George Mason University, Caltrans, the New York and Texas DOTs, Texas Transportation Institute, and Honeywell. At PATH, Steinhassenberger, Hong, Le, and Mark Hickman have been involved at many levels of the preliminary architecture definition and evaluation.

Perhaps the most significant contribution of PATH has been in the area of architecture evaluation. PATH researchers were responsible for the development of the Rockwell Team's Evaluation Plan, describing how to evaluate the technical performance, non-technical issues, risks, costs, and benefits associated with the architecture. A broad view of the evaluation framework is shown in figure 1. At each stage of development and refinement, preliminary assessments have been conducted to provide some feedback to the evaluation process. This has included evaluation of the logical architecture (from the functional analysis), represented by the data flows, data loads, and functions. Similarly, the physical architecture includes the allocation of functions to specific entities (or subsystems, e.g., a private vehicle or the roadside) and a definition of interconnections between entities (e.g., vehicle to roadside). An initial evaluation was used to refine these architecture products. For example, it was decided on the basis of market risks and technical feasibility to support both in-vehicle and centralized/remote-planning functions in the architecture.

Architecture evaluation has proceeded based on a set of ITS market packages, which describe specific modular bundles of physical components and services that will ultimately provide ITS services to users. That is to say, the 33 market packages the Rockwell Team's architecture provide a marketable and modular "packaging" of functions from the 29 user services envisioned in the ITS America National Program Plan. The market packages represent a particular synthesis of the architecture and also a "deployable" bundle of components and services for users. Individuals and public or private organizations could purchase a bundle of certain equipment or services directly as a market package, and thus achieve a certain minimal level of function within ITS. The idea of modular packages allows a user to upgrade to higher levels of technical capability. This preliminary set of market packages has undergone a rigorous analysis of costs, benefits, technical performance, risks, and institutional issues, as shown in figure 1.

Figure 1


[1] The draft ITS national Program Plan envisioned at least 29 user services that fall in the set of intelligent transportation systems.


continued on page 13
PATH Research Presented

AVCC '94—JAPAN
Carl Hedrich was a keynote speaker at the Advanced Vehicle Control Conference '94, held in Tokyo Science City, Japan, Oct. 21-24, 1994. About 225 people from over the world attended, including representatives from universities and industry. The focus was on automatic control applications to automobiles and trucks, including electronic suspensions, traction control, and IVHS. Prof. Hedrich spoke on "Control issues in IVHS."

IFAC—CHINA

ASLAMAR
UC Berkeley researchers John Davis and Rolando Diesta presented papers at the 28th Annual ASLAMAR Conference on Signals, Systems, and Computers, held in Pacific Grove, California from Oct. 31- Nov. 2, 1994. Proceedings will be available in the spring of 1995. The papers were:
- J. S. Davis II and J. P. M.G. Limnartz, "Vehicle to vehicle RP propagation measurements."
- R. Diesta, "Spatial collision resolution for packet-switched multiple-access wireless networks."

SILICON VALLEY
Stein Weissbenber gave a presentation on technology needs for ITS at the Technology Partnership Workshop on Commercial Opportunities for Silicon Valley in Advanced Transportation, on Dec. 8 at the McHenry Convention Center in San Jose.

CAL POLY SAM LUIS OBISPO
Prof. Art MacCarley and the staff of the Transportation Electronics Laboratory (TEL) at Cal Poly SLO held a seminar Dec. 12, 1994 on advanced imaging technologies for traffic surveillance and automobiles.

AJS '94—GAINESVILLE, FLORIDA
The following talks were presented at the AJS '94 Conference on Distributed Interactive Simulation Environments, Gainesville, FL, Dec. 7-9:
- J. Legeros, D. Godbole, S. Sastry, "Simulation as a tool for hybrid control."
- P. Ekhad, D. Khorraramabadi, P. Varaiya, "Synter: An automated highway system simulator."

ATMIS WORKSHOP—ST. PETERSBURG, FLORIDA

CHANTILLY, VIRGINIA
Mark Miller and Y. B. Yin presented a summary of the research work PATH did on its FIWHA contract on AHS Precursor Systems Analyses at the Automated Highway Systems Precursors Conference in Chantilly, Virginia, Nov. 16-18, 1994.
- M. A. Miller, "AHS outlook of the technological and societal issues environment perspective."
- Y.B. Yin, "AHS roadway deployment case: study of U.S. 101 in Los Angeles."

AMERICAN CONFERENCE—BALTIMORE
PATH researchers had two presentations at this conference, held in Baltimore, Maryland, June 29 - July 1, 1994.

NATIONAL ITS SYSTEMS ARCHITECTURE PROJECT—WASHINGTON, D.C.
PATH Headquarters researchers delivered two presentations on behalf of the Southwest Team at the Final Program Review for Phase I, held Oct. 17-24, 1994.


CORNELL UNIVERSITY
Twelve students (six supported by PATH) and two faculty members (S. Sastry and P. Varaiya) were invited to attend the Workshop on Hybrid Systems and Autonomous Control at Cornell in Ithaca, NY, Oct. 28-30, 1994. The following papers were presented:
- M. Brandt, D. Godbole, J. Legeros, S. Sastry, and P. Varaiya, "Verification problems in hierarchical hybrid control systems for intelligent highways."
- A. Deshpande and D. Godbole, "Hibrid control in AHS: the lane change scenario."
- A. Puri and P. Varaiya, "Verification of hybrid systems using timed abstractions."

NIAGARA FALLS, ONTARIO
- P. Silva Kotsko, "Socioeconomic attributes of commuters and unrealiable commuting time."
- Kenneth A. Small and Robert B. Roland, "A discrete choice simulation model of urban highway congestion incorporating travel reliability."

WORLD TRANSPORT TELEMETRICS CONGRESS—PARIS
Steve Shladover and Bert Michael attended the First World Congress on Applications of Transport Telemetrics and Intelligent Vehicle Highway Systems, held in Paris, France, Nov. 30-Dec. 3. Dr. Michael presented "Designing and maintaining intelligent vehicle highway system security policies" (coauthored with Prof. Edgar Sibley of Georgia Mi-
son University and Prof. T.Y. Lin of San Jose State University) and "Formal system specification of critical real-time vehicle control software" (coau-
thored with Dr. Andy Segal of TRW, Sunnyvale).

UNIVERSITY OF YORK (ENGLAND)
Before the Paris congress, Bert Michael gave a lec-
ture at the University of York on assessing the perfor-
mation of algorithms.
Government Selects Consortium for Automated Highway System

In a move that will catalyze development of a nationwide automated highway system, the US Department of Transportation (DOT) recently selected the National Automated Highway System Consortium (NAHSC) as DOT's partner in creating the prototype for an Automated Highway System (AHS). The California PATH program—Partners for Advanced Transit and Highways—is one of ten core members of the Consortium, which comprises representatives of DOT, the aerospace and automotive industries, state and local agencies, the highway-design industry, and two universities. In announcing the partnership, Federal Highway Administrator Rodney E. Slater said, "As we approach the twenty-first century, the development of an automated highway system holds realistic promise of being the next means of strengthening the performance of our nation's highway system, similar to the impact of the interstate highway system in the last half century."

DOT will provide 80 percent of the estimated $210 million in AHS development costs during a seven-year development period, which will include the demonstration of an initial prototype by 1997. The Consortium will provide the rest of the funds. PATH's share of the work will amount to about $25 million, of which $15 million will be funded by the DOT. By 2001 the Consortium must provide the specifications for a full system, to be built during the early part of the twenty-first century.

The other principal members of the Consortium are General Motors, Delco Electronics, Hughes Aircraft, Brechtel, Parsons Brinckerhoff, Caltrans, Martin Marietta, and Carnegie-Mellon University. NAHSC was one of two groups responding to a competitive solicitation for the AHS program announced by DOT in 1993. PATH also participated in the competing proposal, which was led by TRW. Members of the group not selected have been encouraged to become involved in the partnership between DOT and NAHSC.

PATH's Role in Consortium

"This new partnership with GM and the others will provide the infrastructure we need to build and test major components of a prototype system, and to design the full system," says PATH director Pravin Varaiya. "The exciting part is that we now have the vehicles, the electronics, and the communications equipment we need to prove that the concept works."

Varaiya is optimistic that by 1997 the Consortium will be able to demonstrate the feasibility of many ideas that PATH has been working on for up to eight years. PATH researchers have already used a segment of Interstate 15 in San Diego as a testbed for cars fitted with automatic distance and speed controls, and have also investigated other aspects of highway automation, including safety and the potential reaction of users to new technologies. Another significant area of research has been the development of analytical tools and models that allow the evaluation and comparison of new concepts and technologies for intelligent vehicles and highway systems.

Goals for AHS

The long-range goal of an automated highway system is to significantly improve the safety and the efficiency of the nation's surface transportation system through the use of automated vehicle control technologies in both partial and fully automated systems. Ultimately, the system calls for designated highway lanes in which vehicles equipped with such automatic control devices as special sensors, computers, and communications equipment will be controlled by the AHS system, not the driver. These vehicles' steering, braking, and throttle control will be fully automated. The AHS lanes will be integrated with, and an extension of, highways on which cars are controlled by the drivers.

DOT has estimated that a dedicated AHS lane can double or triple the flow rate (in vehicles per hour) of a manual lane, even in adverse weather conditions. AHS will provide uniform driving performance by eliminating the "acceleration effect" of traffic as well as the accelerations, decelerations, and weaving typical of traffic on manual highways. Traffic flow variations caused by human distractions, including dangerous but all-too-human rubbernecking, will also be eliminated.

The Consortium, in cooperation with DOT, will define the system and performance specifications that will be used to deploy AHS early in the next century. Operational tests involving public use of AHS may begin within ten years, and the addition of designated lanes to highways will occur once AHS has been developed into a safe, practical and desirable system—probably in the second decade of the next century.

The demonstration of the AHS prototype will be conducted in accordance with the Interstate Surface Transportation Efficiency Act (ISTEA) of 1991, which calls for the development of an automated highway and vehicle prototype from which future fully automated intelligent transportation systems can be developed. Secretary of Transportation Federico Pena said that by forming the AHS partnership the government is taking "a giant step forward in our goal of improving the safety and efficiency of our nation's surface transportation system through the use of technology." He also said that the fully automated control of vehicles operating in dedicated lanes in high-priority corridors offers the potential for improvements in highway safety, trip predictability, level of service, operation in inclement weather, mobility, and air quality.

"This project fits in very well with the PATH program," says PATH Director Varaiya. "Now we have access to all the resources and expertise of the Consortium partners. It's going to be fun."

FROM ITS Review, November 1994

PATH Visitors

A delegation from the Public Works Research Institute of the Japanese Ministry of Construction (equivalent to the US Federal Highway Administration), headed by Makoto Nakamura, Chief of the Traffic Engineering Division, toured PATH's facilities at the Richmond Field Station on November 11. The delegation, which also included representatives from Sumitomo Electric and Oki Electric, as well as International Fellows from Northwestern University and ITS America, visited US ITS research sites, mainly in Washington, D.C. and the San Francisco Bay Area. ATMIS Program Manager Stein Weisenberger gave a presentation on current PATH projects, and staff engineers Scott Baysinger and Mark Fan arranged for the visitors and their SFVTA hosts, headed by FITWA Traffic Management Engineer Jackie Landman, to take a ride on the test track in an autowhielded car. Delegation members were reportedly very impressed with the technical material and the ride. (One, on emerging from the test car, remarked: "That was surreal.")
Annual PATH Program-wide Meeting at Richmond Field Station

"There are more people this year, the presentations are better, the weather's better, and the food’s better," one Caltrans engineer summed up PATH's program-wide meeting, held at PATH's Richmond Field Station October 13-14. Over 100 people from more than a dozen academic, government, and industrial organizations participated in two days of presentations, research focus group meetings, and demonstrations. During breaks and al fresco lunches, they took advantage of the Field Station's rambling architecture and San Francisco Bay's Indian summer to discuss current research, exchange new ideas, and renew old friendships.

The schedule:

- Welcome Address – Pravin Varaiya, PATH
  Pat Connroy, Caltrans
  Conference Overview – Steve Shladover,
  Steim Weinberger, PATH

SENSORS
- Sensor Fusion – Alice Agogino, UC Berkeley
- Berkeley Sensor and Actuator Center –
  Albert Piana, UC Berkeley
- Vision – Jitendra Malik, UC Berkeley

SYSTEM INTEGRATION and INSTITUTIONAL ISSUES
- National System Architecture – Hong Lu, PATH
- An Integrated
  Physicists/Line
  Access Layer Model
  of Packet Radio
  Architecture –
  Andreas Polychronis,
  USC
- Preliminary Study
  of IVHS Policy
  Issues – Thomas
  Horror, George
  Mason University

ADVANCED TRAFFIC MANAGEMENT SYSTEMS
- A Machine Vision Based Surveillance System for California Roads – Jitendra Malik,
  UC Berkeley
- Freeway Service Patrol (FSP) Evaluation –
  Alex Shabtai, UC Berkeley
- Simulation of ATIS and ATMS Strategies on
  the SMART Corridor – Adolf May,
  UC Berkeley

SAFETY
- Simulation of Collisions – Benson Tongue, UC
  Berkeley
- Software Safety – Nancy Leveson,
  University of Washington
- Heavy-Duty Vehicle – Ioannis
  Kanellakopoulos, UCLA

TESTBEDS
- California Testbed – Pat Connroy,
  Caltrans
- Irvine Testbed – Will Recker, UC
  Irvine
- Cal Poly Testbed – Stephen
  Hookside, Cal Poly San Luis
  Obispo
- TraInfo Evaluation – Y.B. Yim,
  PATH

SYSTEMS, AHS DESIGN
- Railmobile – Stuart Russell, UC Berkeley
- Disguised Modes – Pravin Varaiya, Shastri
  Sastry, Roberto Rovenski, UC Berkeley
- Continuous Planning – Wei Ren,
  UC Berkeley

ADVANCED TRAVELER INFORMATION SYSTEMS
- Route Choice Panel Survey – Paul Jovanis,
  UC Davis
- Socioeconomic Attributes and Impacts of
  Travel Repliability: A Stated Preference
  Approach – Bernreth Small, UC Irvine
- ATIS Learning Experiments – Ryuichi
  Kitamura, UC Davis

VEHICLE CONTROL
- Lateral Control – Masayoshi Tomizuka,
  UC Berkeley
- Optimal Maneuvers – Satish Sundaar,
  Zvi Shiller, UCLA
- Platoons Dynamics – Nick Stabile,
  Frederick Brownow, Michael Zabat, USC
- AMCC – Forrest Ioannou, USC
- Longitudinal Control – Karl Hedrick,
  UC Berkeley
- Fault Detection – Jason Speyer, UCLA

ADVANCED PUBLIC TRANSPORTATION SYSTEMS
- Light Rail System Safety Improvements Using
  IVHS Technologies – A Case Study – Mark
  Hansen, UC Berkeley
- Smart Traveler Evaluation – Randolph Fall,
  USC

DEMONSTRATIONS
- FSP Analysis (UC Berkeley)
- Pre-Trip Information (UC Davis)
- Voice-Activated Pre-Trip Information (UC
  Davis)
- PLANETS – Abidman, Amin, Asad
  Khan, UC Berkeley
- SmartPath – Pravin Varaiya, Farokh
  Bakhti, Delmar Khosravaneh, UC Berkeley

At the Program-wide Meeting (clockwise from upper left):
- Pedro Stamos of USC
- Terry Davide, Caltrans (left) and Victor Rose, UC Berkeley (right)
- Alex Shabtai, UC Berkeley (left)
- and Paul Jovanis, UC Davis (immediately right)
- Thomas Horan, George Mason University, and Keith Chau, Caltrans
- Albert Piana and Karl Hedrick, UC Berkeley
- Stuart Russell, UC Berkeley (seated at left), and Eric Muscalli,
  Cal Poly Pomona (standing)
ITS Impacts on Vehicle Emissions

continued from page 1

CE-CERT researchers are developing a modal emissions model, based on analytical functions that describe the physical phenomena associated with vehicle operation and emissions production, that calculates engine power demand given a specified driving profile (i.e., velocity and grade versus time). Based on emission measurements from CE-CERT's instrumented vehicle (see photo, p. 1), and other modern vehicles, the model can predict second-by-second emission rates for carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NOx). This model emissions model is being integrated with several traffic simulation models in order to quantitatively determine the impacts of ITS technology on vehicle emissions.

Initially, the model emissions model has been applied to the effects of Automated Highway Systems (AHS). In order to get a general idea of AHS-related emissions, we have compared automated driving conditions with non-automated conditions using mathematical formulations of flow-density-speed characteristics. Non-automated highway flow-density-speed relationships can be approximated mathematically by specifying the spacing (or gap) between vehicles required for safe stopping. If one car suddenly brakes, and after a time lag, a second car also brakes without collision. The lower flow-density curve in figure 1 was produced for the case when the first car brakes at 0.9 m/s (2.02 m/s²) and the second car brakes at 0.96 m/s (5.88 m/s²) after one second time lag. This curve is for a single lane and is similar to curves predicted by the Highway Capacity Manual. A similar mathematical formulation can be developed for the flow-density-speed characteristics of an automated highway system consisting of vehicle platoons. Within a platoon of vehicles, the vehicle spacings are much smaller, closely regulated by automated controls. Therefore, platooned vehicles can travel faster at higher densities, thus improving the traffic throughput. A mathematical approximation of the flow-density-speed characteristics for automated traffic is also shown in figure 1, based on platoons of 20 vehicles. The difference between these two curves is substantial. The maximum traffic flow for the automated case is four times that of the non-automated case. The maximum flow for the automated case occurs at an average speed of 100 km/h; for the manual case it occurs at 48 km/h.

CE-CERT's power-demand modal emissions model can be successfully integrated with the SmartPath simulation program developed at PATH for AHS. Simulation programs were carried out to determine average emission rates at different steady-state velocities. The motion parameters, engine power demand, and associated emission rates were calculated for each modeled vehicle in the simulation. Because the follower vehicles within a platoon have very small intraplatoon spacings (on the order of one meter—see figure 2), the aerodynamic drag coefficient of each follower is significantly reduced due to the drafting effect. Using aerodynamic drag reduction data for vehicles in platoons produced by PATH researchers at the University of Southern California, the calculated power demand on the engine and consequently emissions at higher speeds are significantly smaller than in the non-platooning case.

In order to determine total steady-state velocity emissions of an automated lane within an AHS, these emission data were applied to the flow-density curves shown in figure 1. It is important to note that these curves reflect traffic density and flow associated with specified safe space gaps. To generate flow values at lower densities, vehicle speeds greater than the free speed (i.e., the maximum speed a driver would travel on the freeway without interfering with traffic) were used in the calculations. For purposes of generating total link emissions at lower densities, the flow values were adjusted so that the vehicle velocities at low densities were at the constant free speed.

The total CO emissions for a one-kilometer lane are shown as a function of traffic flow for both the manual and automated (platooning) cases in figure 3. There are several key points to note in this figure:

- The maximum traffic flow for a manual lane is 2053 vehicles/hour at an average vehicle speed of 48 km/h. At the same traffic volume, the automated lane produces roughly half as much CO emissions as in the manual case, regardless of whether the platoon size is 15 or 20 vehicles.

- Given the emissions rate for maximum manual traffic volume, roughly twice the traffic volume can occur in the automated lane (regardless of whether the platoon size is 15 or 20 vehicles) to produce the same amount of emissions.

- The emissions associated with maximum traffic flow for an automated lane is roughly twice that of the maximum flow rate of manual driving.

It is important to point out that the emissions associated with higher traffic densities and lower average speeds are underestimated in these curves. Remember that these emissions are calculated based on steady-state velocities, and the negative slope region of the flow-density curve is inherently unstable, leading to stop-and-go traffic. Accelerations associated with stop-and-go traffic will lead to a greater amount of emissions, a topic that is currently under investigation.

This analysis has also ignored the effects of platoon maneuvers that are performed as vehicles enter and exit the AHS at different locations.

Using the SmartPath simulator and the coupled emissions model, we are currently investigating three maneuvers that may have a large impact on emissions production: free-speed accelerations, platoon merging, and platoon splitting. Initial results show that commanded accelerations associated with these maneuvers may cause significant emissions when modeling a modern vehicle with current emission-control technology.
Research is also underway evaluating the emissions impact of ramp metering. It has been suggested in recent years that ramp metering may be counterproductive from an air quality point of view. Many view ramp metering as a traffic control technique that shifts congestion off of the freeway and onto the surface streets, while at the same time inducing more demand on the freeway on-ramps. In order to analyze the impact of ramp metering on air quality, three primary, direct influences that ramp metering may have on vehicle emissions have been identified:

- Freeway traffic smoothing — The primary intent of ramp metering is to smooth the traffic flow on the freeway mainstream and reduce overall delay for freeway travelers. By limiting the input volume to the freeway, overall freeway speeds can be increased. Further, by spacing out merging vehicles from the freeway on-ramps, the probability of acceptable gaps in the freeway traffic is much higher, causing lower perturbations to the traffic flow. The overall traffic flow is smoother and faster, resulting in lower emissions.

- Ramp, surface street congestion — When vehicles on a ramp are metered, congestion can occur on the ramp and associated surface streets under heavy traffic conditions. This congestion is characterized by slow, stop-and-go traffic conditions, leading to higher emissions produced by the vehicles waiting to get on the freeway.

- Hard accelerations from the meters — When a vehicle finally reaches the ramp meter and eventually proceeds onto the freeway, it must accelerate rapidly to reach the freeway traffic speed. These accelerations put an enormous load on the engine and can result in relatively short bursts of high emissions.

Each one of these direct effects is being evaluated independently in our research. Other indirect effects also exist. For example, ramp metering can also significantly reduce the number of freeway accidents, thus improving speeds and leading to lower emissions.

This work is being performed as part of the California PATH program. The research is being led by the author with assistance from Joseph Norbeck, Ramachandra Tudi, Gary Zhang, and Satyajeet Malhotra at UC Riverside.

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**Table 1**

<table>
<thead>
<tr>
<th>Likelihood of Significant Implementation</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Model simplicity</td>
<td>Effect of external impacts on users and non-users</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Ability to deal with many types of future uncertainties</td>
</tr>
<tr>
<td>Guideliness</td>
<td>Ability to support effective policy and regulations</td>
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<tr>
<td>Impactability</td>
<td>Ability to support new deployments in the short run</td>
</tr>
<tr>
<td>Susceptibility</td>
<td>Capacity of the architecture to survive and flourish in the long run</td>
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PATH and National ITS Architecture

To get a group of the implications of a national ITS architecture, PATH has taken the lead in defining a comprehensive evaluation framework that integrates the measures of costs, benefits, technical performance, non-technical issues, and risks. This framework is based on the三维 evaluation criteria given to the contractor team in Phase I. However, these evaluation criteria are not entirely satisfactory in representing either the architecture or its implications for many of the system stakeholders. Instead, PATH has developed a qualitative assessment methodology that allows for evaluation of the architecture based on certain key stakeholders.

PATH also took the lead in a preliminary assessment of the benefits of the Rockwell Team's architecture, including an assessment of the architecture's support for both private sector and public sector involvement in ITS. More tangible, it also included an analysis of the direct benefits to travelers of each of the market package. To support this effort, PATH also conducted detailed simulation of traffic impacts resulting from improvements in traveler information as well as traffic control and incident management. Results of the benefits analysis appear in the Rockwell Team's Initial Performance and Benefits Summary, also under PATH's responsibility in Phase I.

In Phase I, PATH researchers prepared over 1000 pages of documents and made many presentations for DOT, various technical experts, and system stakeholders. If the Rockwell Team is selected for participation in Phase II, California PATH will continue in roles and responsibilities similar to those mentioned above. Phase II, however, will involve a more detailed description of the architecture, as well as more specific advice to both DOT, state and local agencies about how to implement and operate ITS produces and services within this national architecture. This project is an excellent opportunity for PATH to help define the direction of ITS development and deployment well into the future.

Additional information on the national ITS architecture development program or PATH may be obtained from Hong Lo, Mark Hickman, or Stein Wessenberger.

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Below is an update on some recent PATH publications.

A price list that includes research reports, working papers, technical memoranda, and technical notes can be obtained from the Institute of Transportation Studies Publications Office, University of California, 109 McLaughlin Hall, Berkeley, CA 94720

510-642-3558, FAX: 510-642-426.

Abstracts for all PATH research publications can be obtained via the PATH World Wide Web home page on the internet:

https://www-path.itsc.berkeley.edu/

PATH Research Reports

UCBITS/MR/94-20
An Integrated Physical/Link-Access Layer Model of Packet Radio Architecture, Andrew Polyzonos, Contributors: Archie Polyzonos, In-Ku Li, Popovich Fengjie, Changming Sun, all University of Southern California, October 1994, 52$.

UCBITS/MR/94-21

UCBITS/MR/94-22

UCBITS/MR/94-23
Monitoring the San Francisco Bay Area Freeway Network Using Probe Vehicles and Random Access Radio Channels, Jane Paul A.A. Linares, Marcel Wetterman (UCL University), Rick Hammarberg (Bell University), October 1994, 50$ with disk.

UCBITS/MR/94-24
Organizing for IMS: Computer Integration Transportation Phase 1: Results in Caltrans and Highway Transportation Management Center, Randolph W. Hall (University of Southern California), Heng K. Liu, Erik Morge, November 1994, 50$.

UCBITS/MR/94-25
Motion Collision Dynamics and Emergency Maneuvering IV: Intrusion/Proximity Collision Behavior, and A New Control Approach for Motion Control in Vehicle to Vehicular/Personal Traffic - Final Report, Thomas R. Topper, Han-Chung Yang, November 1994, 50$.

UCBITS/MR/94-26

PATH Working Papers

UCBITS/MR/94-16
Brake Dynamics Effect on AHS Lane Capacity, Douglas B. Messier, October 1994, 50$.

UCBITS/MR/94-17

PATH Technical Notes

Tech Note 94-07

Tech Note 94-06

Tech Note 94-05
Robust Motion Maneuvers for AHS, Jonathan Frankel, Luis Alvarez, Roberto Horowitz, Perry L., November 1994, 50$.
Coming Soon...

- Report from the 1995 Transportation Research Board Meeting
- Testing New Lateral Control Software
- AHS Initial Deployment
- What's Coming up for ITS America

... and more!

PATH Publications
California PATH Headquarters
University of California, Berkeley
Institute of Transportation Studies
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Richmond, CA 94804-4698