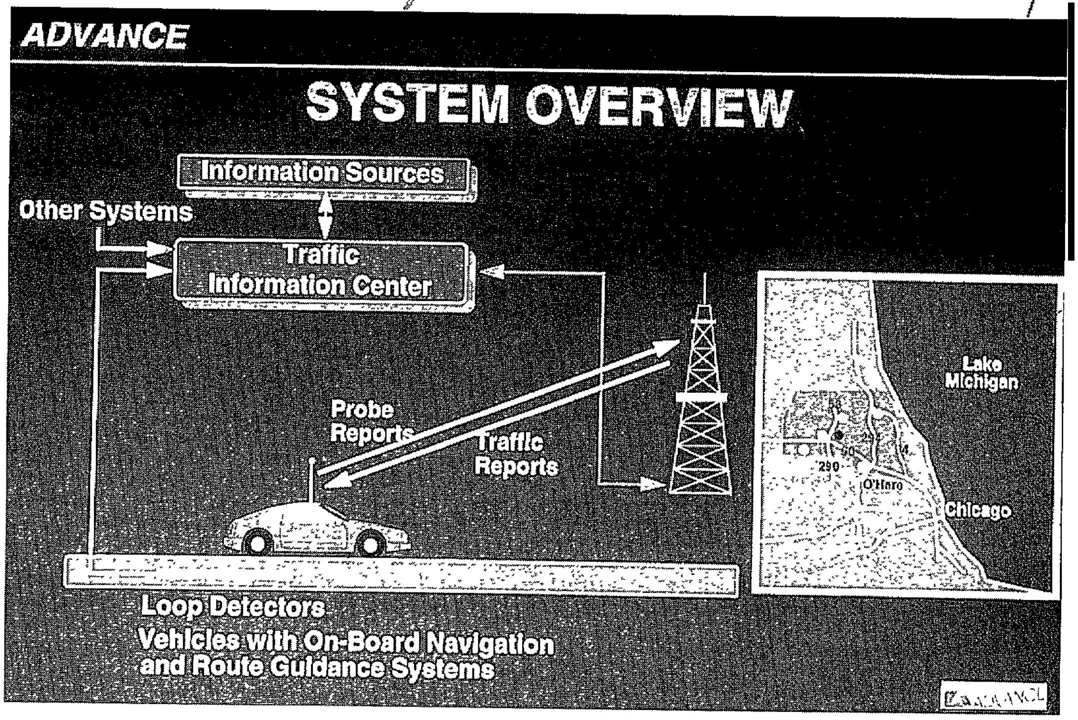
THE ADVANCE PROJECT:

Formal Evaluation of the Targeted Deployment

Volume 3



ADVANCE

ADVANCED DRIVER AND VEHICLE ADVISORY NAVIGATION CONCEPT

DISCLAIMER

THE *ADVANCE* PROJECT:

FORMAL EVALUATION OF THE TARGETED DEPLOYMENT

VOLUME 3

by

Evaluation Manager
Argonne National Laboratory

Evaluation Teams

Castle Rock Corporation, Inc.
DeLeuw, Cather and Company
Northwestern University Transportation Center
University of Illinois-Chicago, Urban Transportation Center

Sponsored by

U.S. Department of Transportation
Federal Highway Administration
Joint Program Office

January 1997

PREFACE

This document reports on the formal evaluation of the targeted (limited but highly focused) deployment of the Advanced Driver and Vehicle Advisory Navigation ConcEpt *(ADVANCE),* an in-vehicle advanced traveler information system designed to provide shortest time route guidance. Argonne National Laboratory (ANL) served as the Evaluation Manager. Organizations that assisted in the evaluations of the various subsystems under test plans developed by Booz*Allen & Hamilton, a support contractor to the Federal Highway Administration's Intelligent Transportation System Field Operations Test program, were the University of Illinois at Chicago Urban Transportation Center (UIC-UTC), Northwestern University Transportation Center (NUTC), and DeLeuw, Cather & Company.

This report contains the results of the targeted evaluation in three volumes. Volume 1 presents the Evaluation Manager's Overview Report prepared by ANL. The overview presents the scope of the evaluation, the data collection protocols, a synopsis of the findings, and a discussion of the validity of the targeted deployment's results. Volume 1 also contains Appendixes A through H. Volume 2 contains Appendixes I, J, and K. Volume 3 contains Appendixes L and M.

The appendixes contain the evaluation test results. The reports of each evaluating organization have been presented in the version received from their respective authors, following completion of the technical and policy reviews conducted according to procedures set by the project's Steering Committee. Appendixes A-G were prepared by UIC-UTC; Appendixes H-J were prepared by NUTC; and Appendixes K and L were prepared by DeLeuw, Cather. Appendix M is a glossary of terms used in these reports, as compiled by ANL.

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THE *ADVANCE* PARTICIPANTS

Founding Parties and Members

American Automobile Association
Federal Highway Administration
Illinois Department of Transportation
Illinois Universities Transportation
Research Consortium
Motorola

Associates

Ford Motor Company
General Motors Corporation
Sun Microsystems, Inc.
Surface Systems, Inc.

Sponsors

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ABBREVIATIONS AND ACRONYMS

AAA	American Automobile Association
AASHTO	American Association of State Highway Transportation Officials
ACG	Access Control Gateway
ADIS	Advanced Driver Information Systems
ADV	*ADVANCE* System
ADVANCE	**A**dvanced **D**river and **V**ehicle **A**dvisory **N**avigation **C**onc**E**pt
AHAR	Automatic Highway Advisory Radio
AI	Artificial Intelligence
ANR	*ADVANCE* Network Representation
ANSI	American National Standards Institute
APTS	Advanced Public Transportation Systems
ASCII	American Standard Code for Information Interchange
ATC	Automated (electronic) Toll Collection
ATIS	Advanced Traveler Information Systems
ATMS	Advanced Traffic Management Systems
AVI	Automatic Vehicle Identification
AVL	Automated Vehicle Location system
AVLM	Automatic Vehicle Locating and Monitoring
BD	Base Data
BSC	Base Station Controller
CASE Tools	Computer Aided Software Engineering Tools
CATS	Chicago Area Transportation Study
CCTV	Closed Circuit TV
CCVE	Closed Circuit Video Equipment
CD-ROM	Compact Disk-Read Only Memory
CLSS	Closed Loop Signal System
COM	RF communications subsystem of *ADVANCE*
COM. 1	RF Coverage Component of the RF Communications Network
COM.2	Fixed Communications Interface
COM.3	Mobile Communications Interface
CRC	CRC Corp. Ltd. (Castle Rock Consultants), subconsultants to DeLeuw, Cather & Co.
CRC Bytes	Cyclic Redundancy Check bytes
CSMA	Collision Sense Multiple Access
C-TIC	Corridor Transportation Information Center
CTS	Clear to Send
CVO	Commercial Vehicle Operations

DAT	Digital Audio Tape
DB	Data Base
DBMS	Data Base Management System
DCCO	De Leuw, Cather & Company
DDS	Detail Design Specification Document #8600
DF	Data Fusion
DIME	Dual Incidence Matrix Encoded files
DRGS	Dynamic Route Guidance System
DS	Data Screening
DSR	Data Set Ready
DTE	Data Terminal Equipment
DTR	Data Terminal Ready
DTTC	Detector Travel Time Conversion
ERS	Emergency Response Service
ETC	Electronic Toll Collection
ETTM	Electronic Toll and Traffic Management
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FTP	File Transfer Protocol
GCM	Gary-Chicago-Milwaukee
GDS	General Design Specification, Document #8500
GIS	Geographic Information System
GPS	Global Positioning System
GUI	Graphical User Interface
HAR	Highway Advisory Radio
HOV	High Occupancy Vehicle
HTTP	Hypertext Transfer Protocol
HUFSAM	Highway Users Federation for Safety and Mobility
HVAC	Heating, Ventilation, Air Conditioning
IBI	IBI Group, Subconsultants to De Leuw, Cather & Company
ICS	Interface Control Specification, Document #8110
ID	Incident Detection
IDOT	Illinois Department of Transportation
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
IUTRC	Illinois Universities Transportation Research Consortium

LAN	Local Area Network
LCD	Liquid Crystal Display
LORAN-C	Long range land-based radio navigation system operated by the U.S. Coast Guard
LSB	Least Significant Bit
MIF	Motorola Intermediate File
MMI	Man-Machine Interface
MNA	Mobile Navigation Assistant
MOE	Measure of Effectiveness
MPO	Metropolitan Planning Organization
NavTech	Navigation Technologies Corporation
NCP	Network Control Processor
NCP/IF	Network Control Processor Interface
NDT	Network Display Tool
NFM	Network Flow Model
NFS	Network File System
NHTSA	National Highway Traffic Safety Administration
NU	Northwestern University
NUTC	Northwestern University Transportation Center
NWCD	Northwest Central Dispatch
OAM	Operations Administration and Maintenance
OD	Origin-Destination
OOA	Object Oriented Analysis
OOD	Object Oriented Design
PI	Principal Investigator
PMP	Project Management Plan, Document #8200
POI	Point of Interest
POP	Project Operations Plan
QA	Quality Assurance
QC	Quality Control
RAM	Random Access Memory
RD-LAP	Radio Data Link Access Procedure
RF	Radio Frequency
RFSRV	RF Server
RISC	Reduced Instruction Set Computer

RNC	Radio Network Controller
ROM	Read Only Memory
RPC	Remote Procedure Call
RPCGEN Tools	Remote Procedure Call Generation utility
RPMIF	Radio Packet Modem Interface
RTS	Request to Send
RXD	Received Data
SAE	Society of Automotive Engineers
SC	Steering Committee
SCADA	Surveillance Control and Data Acquisition
SE	Static Estimates
SIF	Standard Interchange File
SP	Static Profiles
SPU	Static Profile Update
SSI	Surface Systems Incorporated
SVRS	Stolen Vehicle Recovery System
TAC	Technical Advisory Committee
TBD	To Be Determined
TCP/IP	Transmission Control Protocol/Interface Protocol
TFHRC	Turner-Fairbank Highway Research Center
TIC	Traffic Information Center
TIGER	Topologically Integrated Geographic Encoding & Referencing files
TLI	(AT&T) Transport Layer Interface
TRB	Transportation Research Board
TravTek	Travel Technology
TRF	Traffic Related Functions
TSC	Traffic Systems Center
TT	Travel Time
TTL	Transistor-Transistor Logic
TTP	Travel Time Prediction
TXD	Transmitted Data
UDP	Universal Data Protocol
UIC	University of Illinois at Chicago
UIC-EECS	University of Illinois at Chicago - Electrical Engineering and Computer Science Department
UK-UTC	University of Illinois at Chicago - Urban Transportation Center

V & V	Verification & Validation
V & V Plan	Verification & Validation Plan, Document # 8300
V & V Team	Verification & Validation Team
VNIS	Vehicle Navigation and Information Systems
YD	Yoked Driver

APPENDIX L

ADVANCE

Advanced Driver and Vehicle
Advisory Navigation Concept

System Overview: Insights and Achievements

DISCLAIMER

ADVANCE

ADVANCED DRIVER AND VEHICLE ADVISORY NAVIGATION CONCEPT

Illinois Department of Transportation
Federal Highway Administration
Motorola
Illinois Universities Transportation Research Consortium
American Automobile Association

Insights & Achievements Compendium
Document # 8465.ADV.01

Prepared by: De Leuw, Cather & Company

Issue Date: January 8, 1997

ADVANCE INSIGHTS & ACHIEVEMENTS

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EXECUTIVE SUMMARY

ADVANCE [Advanced Driver and Vehicle Advisory Navigation ConcEpt] was a public/private partnership conceived and developed by four founding parties. The founding parties include the Federal Highway Administration (FHWA), the Illinois Department of Transportation (IDOT), the University of Illinois at Chicago and Northwestern University operating together under the auspices of the Illinois Universities Transportation Research Consortium (IUTRC), and Motorola, Inc. The major responsibilities of each party are fully described in the Project agreement. Subsequently, these four were joined on the Steering Committee by the American Automobile Association (AAA). This unique blending of public sector, private sector and university interests, augmented by more than two dozen other private sector participants, provided a strong set of resources for *ADVANCE.*

The *ADVANCE* test area covered over 300 square miles including portions of the City of Chicago and 40 northwest suburban communities. The Project encompasses the high growth areas adjacent to O'Hare International Airport, the Schaumburg/Hoffman Estates office and retail complexes, and the Lake-Cook Road development corridor. It also includes major sports and entertainment complexes such as the Arlington International Racecourse and the Rosemont Horizon. The population in the area is more than 750,000.

The system architecture of *ADVANCE* incorporates several key concepts: distributed intelligence (all route planning is performed in the vehicle); a hierarchical road network database (for higher performance in all map-related functions); vehicles as traffic probes (for accumulating real-time information); open (non-proprietary) radio frequency (RF) data communications protocol; and driver interface. The system had four (4) subsystems, namely the Traffic Information Center (TIC) which contains the central processing facility and operator interface; the Traffic Related Functions (TRF) which contains the traffic algorithms, which typically coexist with TIC software on the TIC central computer; the Mobile Navigation Assistant (MNA) which contains invehicle route planning and display capabilities; and the Communications subsystem (COM) which provides message carrying capability between the TIC and the MNA. The TIC and the TRF were the direct responsibility of the Universities, while the MNA and the COM were the responsibility of Motorola.

The *ADVANCE* Project's primary role in advancing Intelligent Transportation Systems (ITS) technology was the operational test of the use of probe vehicles for real-time traffic information on an arterial and expressway network. It included the development and implementation of techniques to fuse data from such diverse sources as probe vehicles, fixed detectors and anecdotal reports to provide dynamic route guidance information to drivers. The vehicles, equipped with the navigation equipment, served as roving traffic probes which the vehicles reported travel times for the road links traversed within the test area. This information was automatically prepared by on-board equipment and transmitted over a radio frequency data network to the Traffic Information Center (TIC). Closed loop traffic signal detectors and expressway detectors also provided volume and occupancy information at regular intervals which the TIC automatically fused with other data to detect incidents and congestion.

Issues of technology, liability, intellectual and property rights, project management styles, and desired project outcomes routinely arose and were resolved during the *ADVANCE* Project. This compendium sunmarizes the *ADVANCE* experience, including obstacles encountered and methods used to overcome them in the development, implementation and deployment of the *ADVANCE* system. Participants have agreed that the overall experience was challenging and productive: a positive as well as a pioneering example of public/private partnerships to develop state-of-the-art transportation systems.

The purpose of the Insights & Achievements Compendium is to develop a summary of lessons learned from *ADVANCE* which could be applicable to other project deployments and operational tests. It is an attempt to try to answer the questions: "If you had to do it over again, what would you do differently? What would you do the same? What have you learned that you think would be useful to others?" A brief summary of each Insights and Achievements paper is presented below.

<u>Contractual and Management Challenges</u>

The *ADVANCE* Project is a prime example of a public-private partnership. Such partnerships seek to combine the capabilities and benefits of public agencies and private organizations, both for-profit and not-for-profit, in advancing their jointly-held and individual objectives. The *ADVANCE* Operational Test was, at its inception, proposed to be the largest field test of dynamic route guidance in the United States. The scope of the test and the public-private nature of *ADVANCE* was a challenge to the normal contracting and operating procedures of all participants. This paper covers the development of the *ADVANCE* concept as well as the contractual arrangements used in the project. It provides insights on the unique nature of *ADVANCE* and the methods used to manage the project.

<u>Development of the RF Subsystem</u>

The development of the RF subsystem for *ADVANCE* met the challenges of matching existing communications technology with new concepts from the ITS arena. Providing two-way wireless communications between mobile users and the Traffic Information Center (TIC) meant that a variety of options could be used. The intent to focus on proven technology narrowed the field, however new approaches within the ITS world were also explored. Once the desired option was selected, the challenges lying within it presented unanticipated problems that needed reasonable solutions for all related subtasks to proceed. The *ADVANCE* experience is expected to offer valuable insight to future developers of RF communications for ITS applications. This report documents the development of the *ADVANCE* RF subsystem, the alternatives and subsequent challenges encountered, and the lessons learned.

System Intenration Challenges

This paper focuses on the integration aspects of the *ADVANCE* system. The majority of the findings relate to how the system integration team was able to increase communication between the system and subsystems and component designers, developers and integrators. Also, discussed is the importance of communication within each organization and the need to remain open and accessible with respect to transfers of information. The findings also emphasize the need for thorough documentation to be developed at each stage of the project. To ease the burden on the integration process, the use of releases is a very effective concept. However, in order for it to function properly, work must remain on schedule. The findings relate the difficulties in managing subsystems at different release levels and the need for thorough testing by designers and developers prior to releasing subsystems to integrators.

Field Data Collection Activities

This paper documents how the evaluators and other parties integrally involved with the *ADVANCE* Targeted Deployment implemented and maintained an evaluation data collection effort consistent with plan specifications, despite encountering numerous obstacles during the testing period. Because of the extremely tight time frame in which the various *ADVANCE* tests could be conducted, it was imperative that the means and procedures established for data collection be as free from delay and deviation as possible. The report describes these means and procedures, both those adopted from the beginning and those for which necessity arose as tests progressed. It highlights methods which worked especially well and those which were found to be in need of adjustment, and also discusses the workability of those adjustments.

Technical Challenges

In developing *ADVANCE*, both as a whole and each of its various subsystems, the state of the art of the various technologies was reached. In addition, *ADVANCE* was developed using a series of releases with each new release adding additional functionality to the previous one. Thus, each new release of a subsystem had to perform its intended purpose and continue to work with the other subsystems. Complicating this process, was that the development was done by a variety of personnel, from different corporate backgrounds operating in distinct, separated geographical sites. The result was to create numerous technical challenges in developing *ADVANCE*. This report documents the technical challenges in developing *ADVANCE* by noting what they were, what their impact was and how the challenges were met and overcome. Readers specifically interested in lessons learned on the RF communications system as well as the TRF algorithms should read the respective reports.

Estimating Environmental Effects

This paper is intended to link some of the specific test experiences with the existing literature on ITS effects. It thereby draws inferences how driver behavior under an *ADVANCE* type of ATIS deployment is likely to affect the vehicular emission results of such deployment and, by extension, of other ATIS concepts. Because the future availability of navigational aids and real-time traffic information (i.e., ATIS without advanced traffic management) is far more likely to be determined by private vendor/developer initiative and investment than by major public works projects, the direct benefits of these ATIS concepts may be limited to the individual motorists who purchase such services. In fact, estimation of the overall distribution of benefits and disbenefits among users and non-users is a multi-layered and complex process. This paper also addresses the issue ofwhether the direct benefits to such a comparative minority of motorists, those equipped with real-time ATIS capability such as dynamic route guidance, can in any consistent way generate environmental benefits for everyone in the airshed, motorists and non-motorists alike.

Recruitment of Volunteer Drivers

A key element of the field test was providing *ADVANCE* in-vehicle systems for use by volunteer drivers in their routine, local trip-making. A major challenge in the implementation of this test was recruiting volunteer drivers to utilize the system. The *ADVANCE* recruitment effort was designed to fill this need, to attract, select, and train sufficient drivers to meet test quotas. The sample of drivers needed to meet certain research and risk management criteria, to be of sufficient size, and, since *ADVANCE* was partially publicly-funded and thus subject to public scrutiny, to be the result of an unbiased process. The recruitment effort was originally designed to meet a quota of drivers from 3,000-5,000 households using their own vehicles for periods up to two years. This presented a large and complex recruiting challenge. Ultimately, *ADVANCE* adopted a Targeted Deployment scheme, under which approximately 80 households used the test vehicles. Still, many elements of the original recruitment process design were utilized under the Targeted Deployment. This effectively became a large prototype test of the original recruitment plans. As such, the resulting experience offers useful guidelines for the design of future Intelligent Transportation Systems (ITS) field tests using volunteer drivers.

Probes and Detectors

The main purpose of this white paper is to detail *ADVANCE*' s experience with probe and detector traffic data reports. This discussion addresses the effectiveness of design decisions and the performance of both probes and detectors in the context of both the *ADVANCE* operational test and ATIS systems in general. The purpose of both probes and detectors is to gather information about prevailing traffic conditions on a roadway link in order to provide route guidance to vehicles which have the necessary on-board equipment. The key information required by vehicles is link travel time. Therefore, this report is mainly confined to the problem of estimating link travel times from probe and detector reports.

Institutional Issues

This paper emphasizes specific institutional issues encountered and resolved in the performance of the *ADVANCE* operational test. The major institutional issues for *ADVANCE* related to the progression of an Intelligent Transportation System (ITS) technological development effort from concept to reality. At times, the institutional issues encountered in *ADVANCE* caused minor delays in the Project because they caused uncertainty in completing administrative responsibilities according to schedule. However, despite these obstacles, the Parties made the commitment to work together to satisfactorily complete the goals and objectives established for the Project. Equally important, the institutional issues identified and resolved in *ADVANCE* will serve as valuable lessons for future ITS projects.

Implementation of Algorithms

Development and implementation of new traffic analysis algorithms in a real world application environment with a fixed time schedule requires coordination and collaboration among algorithm developers, implementation programmers, developers and installers of the technology to be used for data collection and communication and the operators of the implemented system. Effective management of this process requires a carefully structured work program which includes adequate time for completion of all required tasks and which recognizes interdependencies among tasks. This work program must be flexible enough to respond to changes inherent in the development of technology or algorithms. This paper describes the procedures undertaken to maintain coordination among developers, program implementors and operators and describes implementation problems which arose and their treatment. It also describes the use of simulation data for initial development and highlights the importance of field data for final refinement and validation.

Targeted Deployment

This paper examines the issues and options considered in the decision to redirect the originally planned deployment of 3,000 in-vehicle dynamic route guidance systems to a deployment of less than 100 units as part of the Targeted Deployment. Market conditions and available technology changed since *ADVANCE* first was proposed. Technologies for vehicle navigation systems took longer to develop and implement than originally thought. The availability of other commercial in-vehicle navigation systems anticipated at the project inception also lagged. It was the consensus of the *ADVANCE* Steering Committee that commercially available systems using dynamic information were still some time away from being available in the U.S. market place and also that the platform established for *ADVANCE* was likely not to be a commercially viable option. It was therefore decided that the Targeted Deployment would best serve the needs of the project partners and the ITS industry as a whole. It was believed that a significant portion of the original goals and objectives could be met under a Targeted Deployment. This option allowed for limited testing of an in-vehicle dynamic route guidance system at a significantly lower budget. It expedited the sharing of state-of-the-practice results associated with the operational test. The *ADVANCE* success in achieving almost every one of its original goals and the wealth of data collected in this more limited effort are enumerated as a testament to the decision to implement the Targeted Deployment.

Safety

The purpose of the Safety Evaluation of the *ADVANCE* Project was to assess whether drivers drive and navigate more or less safely with the MNA than without it. The project also intended to increase the body of scientific knowledge on how drivers operate a vehicle while navigating. The study examined the effects of four navigation scenarios on driving and navigation performance. The navigation scenarios were: (1) MNA with voice supplement, (2) MNA without voice supplement, (3) a paper map, and (4) a typed list of directions. The latter two scenarios served as control conditions. In addition to the four navigation scenarios, the study examined the influence of age and experience with the MNA on driving performance and navigation. Sixty drivers split by age and gender drove each of the four different navigation conditions. Analysis of the data suggests that no element of the MNA system is particularly hazardous to driving safety. Appendix L. provides insights into the strengths and weaknesses of video and digital gathering equipment, data management practices, blind data analysis techniques, etc. An exploration of the consistencies between this and similar studies, such as for the TravTek deployment in Florida, in included.

1.0 INTRODUCTION

1.1 Acronyms and Definitions

For a complete listing of acronyms, definitions and abbreviations refer to Appendix A of the *ADVANCE* System Definition Document, #8020.ADV.06. To aid in reading this report, several of the more common terms are defined below.

AAA-CMC - American Automobile Association - Chicago Motor Club.

ADVANCE - Advanced Driver and Vehicle Advisory Navigation ConcEpt

ANL - Argonne National Laboratory. ANL was Evaulation Manager for the *ADVANCE* Project .

ATIS - Advanced Traveler Information System

CATS - Chicago Area Transportation Study, the metropolitan planning organization for the Chicago area.

Cellular *999 - Motorist information and retrieval service operated by the Illinois State Toll Highway Authority to obtain traffic incident information from motorists with cellular phones.

COM - RF Communications subsystem of *ADVANCE.*

Differential GPS - A correction applied to GPS positioning to improve accuracy.

ETC - Electronic Toll Collection

FHWA - Federal Highway Administration. One of the founding Parties. FHWA is responsible for the overall evaluation of the *ADVANCE* Project.

GPS - Global Positioning System, a government-owned system of 24 earth-orbiting satellites that transmit data to ground-based receivers. GPS provides extremely accurate latitude and longitude ground position in WGS-84 coordinates. However, for U.S. strategic defense reasons, deliberate error(called selective availability) is introduced into the code that is provided for civilian users.

IDOT - Illinois Department of Transportation. One of the founding Parties. IDOT is responsible for providing project management for *ADVANCE* and for operating the TIC.

ITS - Intelligent Transportation Systems.

IUTRC - Illinois Universities Transportation Research Consortium. One of the founding Parties. IUTRC is a non-profit corporation owned by Northwestern University, the University of Illinois at Chicago, the University of Illinois at Urbana-Champaign, and the Illinois Institute of Technology.

Link - A pair of adjacent segments and its associated data within a given network layer. A link consists of the portion of road from the detected beginning of a segment to the detected beginning of one of its successor segments.

Memory Cards - A plug-in computer memory card containing prerecorded information. May function as mass storage for onboard navigation systems.

MNA - Mobile Navigation Assistant. An in-vehicle navigation system designed and built by Motorola that determines vehicle position, performs route planning based on current traffic information, and provides dynamic route guidance information to the driver.

NUTC - Northwestern University Transportation Center. Northwestern University is a member of the IUTRC.

NWCD - NorthWest Central Dispatch an emergency dispatch service for several of the communities in the *ADVANCE* test area.

Motorola - One of the founding Parties. Motorola is providing the in-vehicle system as well as the RF communications systems.

RF - Radio Frequency.

Segment ID - A unique ID that identifies each roadway segment. The ID consists of twenty-three (23) bits as assigned by Navigation Technologies, the map database provider.

SSI - Surface Systems Incorporated, a provider of inroad and roadside weather sensors.

Static Profile - Static information of the roadway link including day type, link ID and average travel times for a specific time period.

TAC - Technical Advisory Committee. Responsible to the Steering Committee for malting recommendations on system design and system direction.

TIC - Traffic Information Center. The TIC consists of the hardware, software, and operations personnel in a centralized facility. It communicates to and receives information from probes and external systems.

Travel Time - The time it takes to travel from one end of a link to the other.

TSC - Traffic Systems Center. Operated by IDOT to monitor and control the flow of traffic on expressways within the Chicago area.

UIC - University of Illinois at Chicago. UIC is a member of the IUTRC.

UIC-EECS - University of Illinois at Chicago, Department of Electrical Engineering and Computer Science. Responsible for the development of the TIC and coding of the TRF algorithms.

More specific terms are provided at the beginning of each Insights and Achievements paper.

1.2 Authors

The authors of the Insights and Achievements Papers were directly involved in the development and deployment of *ADVANCE.* They represent the main designers, developers, integrators and evaluators of *ADVANCE* and its subsystems. Respective authors are introduced in the beginning of each Insights and Achievements paper.

1.3 Intended Audience

The Insights and Perspectives Compendium is intended to provide useful information to project managers, system developers, and system integrators of future similar ITS implementations. It is intended for those that are technically interested in the *ADVANCE* Project and have a basic understanding of the project.

1.4 References

The following documents provide more detailed information on the *ADVANCE* Project:

- Goals & Objectives Document, #801 0.ADV.04
- System Definition Document, #8020.ADV.06-2.0
- Requirement Specifications, #8100.ADV.052.0
- Interface Control Specification, #81l0.ADV.052.0
- Project Management Plan, #8200.ADV. 10

- Verification & Validation Program Plan, #8300.ADV.06
- Integration Program Plan, #8320.ADV.04
- Subsystem Integration Test Plan, #8330.ADV.03
- System Integration Test Plan, #8340.ADV.03
- Evaluation Program Plan, #8400.ADV.04
- Evaluation Management Plan, #8450.ADV.00
- Evaluation Managers Report, #8460.ADV.00
- General & Detail Design Document, #8500&8600.ADV.01
- TIC Console Operator's User Manual, #8700-3.2
- TIC Policies & Procedures Manual, #8750.01
- MNA Operations Manual, #8800

All of the above documents and other related, non-proprietary information are available on the Internet at the following address:

- http://ais.its-program.anl.gov/

1.5 Report Organization

This report is organized as follows. Section 1 presents an introduction to the report, including acronyms and definitions, authors, intended audience, references and report organization. Section 2 presents the background of *ADVANCE,* including project history, participants, technical components and test area. Section 3 outlines the overall evaluation program for *ADVANCE* including the evaluation roles and responsibilities of the participants. Section 4 summarizes the contents of each Insights and Achievements paper. Section 5 incorporates the highlights of each individual paper into the overall findings of the *ADVANCE* Project. Finally, a complete copy of each paper is included in the Appendices of the Compendium.

2.0 BACKGROUND

2.1 The *ADVANCE* System

ADVANCE was a joint public-private venture involving the Federal Highway Administration (FHWA), the Illinois Department of Transportation (IDOT), Motorola, the Illinois Universities Transportation Research Consortium (IUTRC) which includes Northwestern University and the University of Illinois at Chicago, and the American Automobile Association (AAA) in cooperation with local governments and public agencies. *ADVANCE* was a field operational test of dynamic route guidance using vehicle probes as the prime source of real time infomation. The test measured road network performance, monitored vehicle locations, detected incidents and produced driver guidance infomation in the context of a suburban arterial network. The vehicles, equipped with the navigation equipment, served as roving traffic probes. As probes, the vehicles reported travel times for the road links traversed within the test area. This information was automatically processed by on-board equipment and transmitted over the RF data network to the Traffic Information Center (TIC). Additionally, closed loop traffic signal detectors and expressway detectors provided volume and occupancy information at regular intervals which the TIC automatically fused with other data to detect incidents and congestion. Anecdotal reports of incidents were also relayed (either in voice or electronic form) to the TIC.

The first concepts of *ADVANCE* were developed beginning in 1989. The July 9, 1991 IVHS Agreement for the *ADVANCE* Project established the mutually agreeable terms to design, develop, implement and evaluate *ADVANCE.* The initial plan was to install up to three thousand in-vehicle units for a period of up to two years. The realization of the Targeted Deployment, see Section 2.3, saw the installation of approximately 75 in-vehicle units during 1994 and early 1995. Evaluation data collection followed and was completed by the end of 1995. System analysis, evaluation and documentation was performed throughout 1996.

The basic concept of *ADVANCE* was as follows:

- The *ADVANCE* vehicles had installed equipment that was capable of determining the vehicle location, selecting the “best” route to the driver’s destination, and providing route guidance instructions to the driver,

- Actual travel times were determined by these probe vehicles as they traversed the test area and this inforination was transmitted over a radio system to the TIC.

- The TIC collected real-time traffic information from the vehicles and other data sources, and processed it through incident detection and travel time prediction algorithms. It then transmitted revised estimates of travel times to the probe vehicles.

- The on-board vehicle equipment determined if the revised traffic information affected the current route. If there was an impact, the driver was presented with a better route to select in order to avoid the traffic incident or congestion.

- As the *ADVANCE* probe vehicles collected additional information, the updated travel times were used to improve the body of knowledge for travel conditions in the test area.

As the lead public sector Party in the *ADVANCE* area, IDOT had responsibility for project management. In carrying out its responsibilities, IDOT contracted with De Leuw, Cather & Company to provide system engineering services and system integration functions for the project. De Leuw, Cather & Company was assisted by Castle Rock Consultants and the IBI Group. The American Automobile Association provided insights on the recruitment and training of volunteer drivers, designed a Help Center for system users, and provided motorist aid services throughout the project. The IUTRC was responsible for development of the Traffic Information Center. Motorola developed the invehicle hardware and software, and provided the Communications equipment. The FHWA, through a contract with Argonne National Laboratory, was responsible for project evaluation.

The *ADVANCE* System had four major subsystems:

- The **Mobile Navigation Assistant (MNA)** determined the vehicle position and provided the route planning and guidance information to the driver. It also prepared the travel time messages for transmission to the TIC. The MNA was an in-vehicle unit. Motorola was responsible for design and installation of the in-vehicle equipment (global positioning satellite receiver, navigation system, route planner, CD-ROM-based map database, and user interface display head).

- The **Traffic Information Center (TIC)** provided the central computer facilities, the repository of *ADVANCE* information, and communication interfaces with the other processes and external entities. It also provided the console system which contained the operator interface to the TIC. IUTRC was assigned responsibility for procuring the hardware and developing software for the TIC.

- The **RF Communications Network (COM)** provided two-way radio communications between the TIC and the MNAs in the probe vehicles. This RF network supported the data communication requirements of the MNA and the TIC. Motorola was responsible for providing the RF communications equipment for transmitting messages between the TIC and equipped vehicles.

- **Traffic Related Functions (TRF)** resided on-line in the central computer facilities of the TIC and off-line in other computers. This process performed the data fusion, Static Profile generation, incident detection and travel time predictions for the roadways in the test area. Abnormal travel situations were identified for broadcast to the probe vehicles so that the MNAs' dynamic route guidance system had current information available. The Static Profiles were generated off-line. The updated Static Profiles were then stored in the static database in the TIC and on the CD in the vehicle. IUTRC developed and implemented the algorithms that flagged incidents in the network and generated travel time predictions for transmission to the probe-equipped vehicles.

Figure 2-1, *ADVANCE* Context Diagram, depicts *ADVANCE* and the extemal entities that interfaced with *ADVANCE. ADVANCE* received information from, and distributed information to a variety of external sources. Incoming and outgoing information is represented by data flows.

Starting with the central *ADVANCE* System, then continuing counterclockwise, the external entities and the type of information exchanged were:

ADVANCE The central circle represents the *ADVANCE* system.

Continuing from the lower right hand corner:

TIC Console Operator: TIC operators monitored the system, handled non-electronic incoming data from anecdotal sources, and provided the necessary input for incident detection. Otherwise, the TIC was designed to primarily operate without the intervention of an operator. IDOT assumed responsibility for operation of the TIC.

Driver: These were people that *ADVANCE* was directly serving. The drivers of the *ADVANCE* probe vehicles interacted with the system through the MNA's man-machine interface.

Vehicle: The vehicles used for *ADVANCE* included approximately 75 private, project, and public vehicles for the Targeted Deployment phase. These vehicles provided the platform for mounting the mobile navigation equipment and also functioned as probes. Eight automobile manufacturers (Ford, General Motors, Honda, Mercedes, Peugeot, Saab, Toyota, and Volvo) donated vehicles for project use.

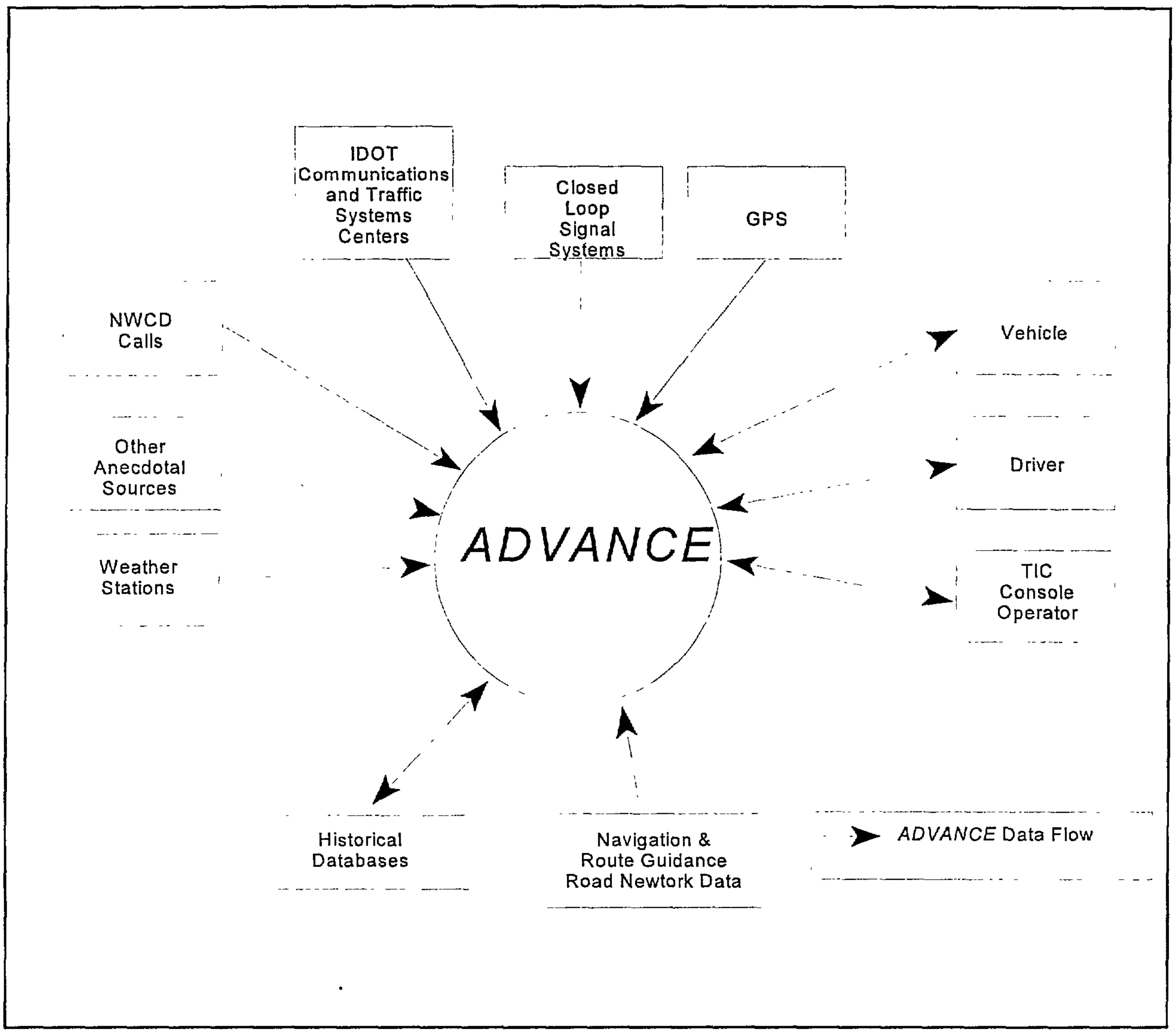

Figure 2-1 - *ADVANCE* Context Diagram

GPS: A Global Positioning System (GPS) was used by the MNA as an aid in determining the location of each probe vehicle (by providing an approximate position to the MNAs map matching and dead reckoning system.) A differential correction was also used to place vehicle locations within 15 meters. Note that GPS was not the primary method of determining position and that the MNA's vehicle positioning system was normally capable of determining an accurate position without GPS.

Closed Loop Signal Systems: The TIC received information from closed loop signal systems installed in the test area. This data was incorporated into the data fusion process to assess travel conditions and detect incidents. It was also used to evaluate and validate travel time data received from probe vehicles. The interface was automated with incoming data being transmitted every five (5) minutes. Traffic volumes and occupancies were transmitted.

IDOT Communications Center: Roadway maintenance and construction information from he Communications Center was forwarded to the TIC via fax. The information was entered by operators into the system. This information was used in the data fusion process for incident detection and travel time prediction.

IDOT Traffic System Center: Expressway congestion information from the IDOT Traffic Systems Center (TSC) was used in the data fusion process for incident detection and travel time prediction. Information received from the TSC did not require an operator interface.

Northwest Central Dispatch (NWCD): An emergency dispatch service for several of the communities in the *ADVANCE* test area. Once received at the TIC, NWCD information was entered manually by the TIC operators.

Other Anecdotal Sources: This anecdotal information aided the data fusion process in identifying incidents and predicting travel times and conditions on the roadways. Information was received via fax and telephone and was entered into the system by an operator.

Weather Stations: Weather information, received from a remote weather station and roadway sensors, was displayed within the TIC.

Historical Databases: The *ADVANCE* system had a static profile database residing on the TIC. This database contained historical network travel times by roadway links to serve as a base with which to compare real-time information for incident detection and travel time prediction. The initial link travel time estimates were developed by combining estimates from a network flow model, an estimation of the origin-destination matrix, and a modified version of the network configuration provided by the Chicago Area Transportation Study (CATS). Specialized software was then used to generate the initial static profile database. The static profile database was updated periodically to reflect the latest travel conditions. The new static profile was placed in the MNAs and TIC with each update.

Navigation & Route Guidance Road Network Data: A complete electronic media database of the road network, provided by Navigation Technologies, served as the road network database. This included location coordinates, travel directions, road classification, regulations, and other related information affecting route planning and route guidance.

2.2 Test Area

ADVANCE was implemented in an area covering more than three hundred (300) square miles in the northwest suburbs of Chicago. Approximately seven hundred and fifty thousand (750,000) people lived in the area during the test. This area was typical of modern suburban developments and had significant traffic congestion problems. Typical journey times were of sufficient duration to make route changes an option to drivers. The road network in the area offered numerous alternatives for most trips. Figure 2-2, ADVANCE Test Area Map, presents the project test area and its boundaries.

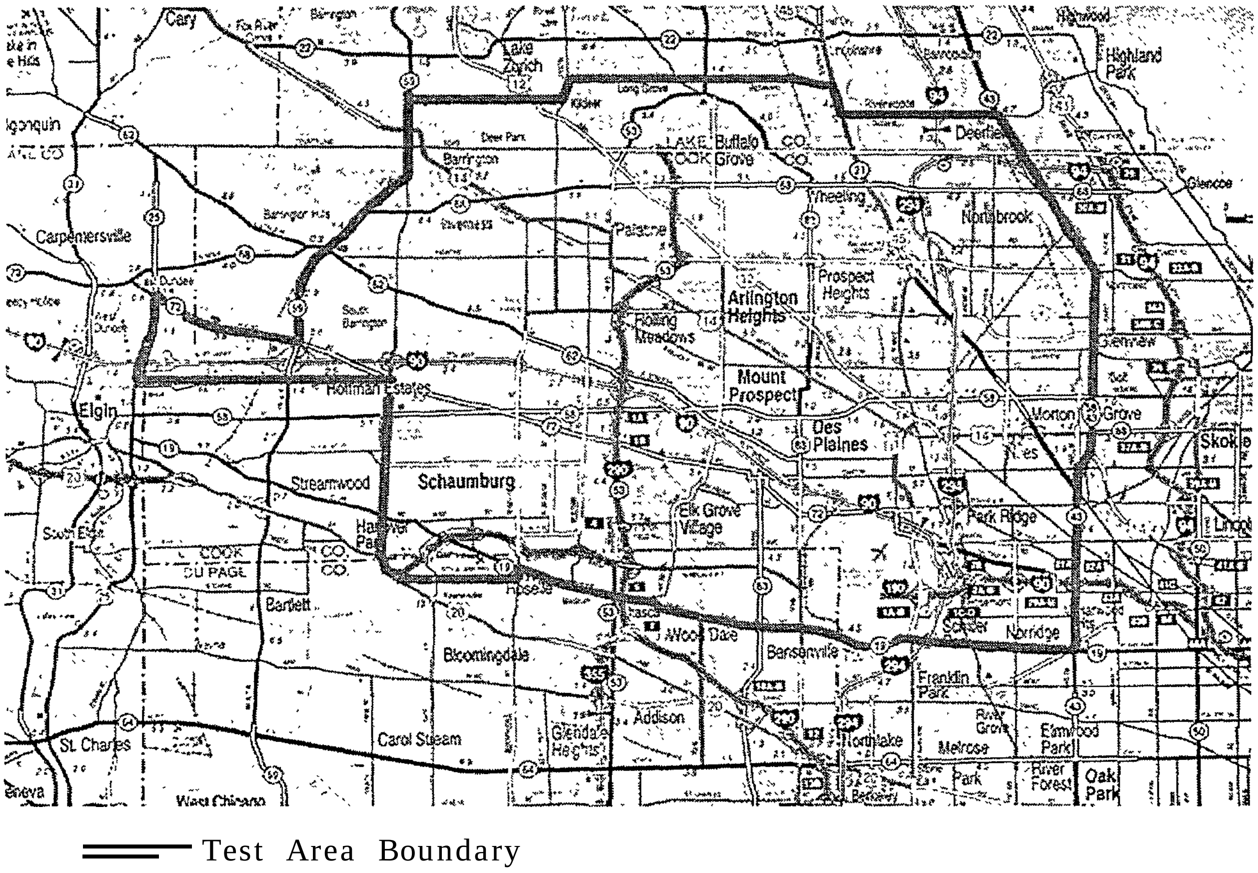

Figure 2-2 *ADVANCE* Test Area Map

The boundaries are defined as follows:

- The eastern boundary was IL-43 from the intersection with Irving Park Road at the southeast corner to the intersection with Deerfield Road at the northeast corner.

- The northern boundary included Deerfield Road from IL-43 to IL-2 1 (Milwaukee Ave.); Milwaukee Avenue from Deerfield Road to Aptaltisic Road; Aptaltisic Road from Milwaukee Avenue to IL-83; IL-83 from Aptakisic Road to Robert Parker Coffin Road; Robert Parker Coffin Road to McHenry Road; McHenry Road from Robert Parker Coffin Road to Cuba Road; Cuba Road from McHenry Road to Quentin Road; Quentin Road from Cuba Road to the north, down to Cuba Road again; Cuba Road from Quentin Road to IL-59.

- The western boundary included IL-59 from Cuba Road to IL-72; IL-72 from IL-59 to Beverly Road; Beverly Road from IL-72 to Shoe Factory Road; Shoe Factory Road from Beverly Road to Barrington Road; Barrington Road from Beverly Road to US-20.

- The southern boundary included US-20 from Barrington Road to Bartels Road; Bartels Road from US-20 to Central Avenue; Central Avenue from Bartels Road to Roselle Road; Roselle Road from Central Avenue to IL-19 (Irving Park Road); Irving Park Road from Roselle Road to IL-43.

2.3 Targeted Deployment

As *ADVANCE* developed, the Public/Private Partners learned much about the technologies involved. *ADVANCE* also witnessed evolution in technology and market conditions. When *ADVANCE* reached the important stage between system development and deployment, prior to installation of in-vehicle units, the public and private entities involved with *ADVANCE* reviewed the original scope and goals of the project.

Market conditions and available technology had changed since *ADVANCE* first was proposed. Market conditions which were anticipated to support a large scale implementation of in-vehicle navigation systems did not occur as quickly as anticipated. This was apparently due to a number of factors including an inability to provide a system at a price which would be attractive. Technologies for vehicle navigation systems took longer to develop and implement than originally thought. The availability of in-vehicle navigation systems anticipated at the project inception also lagged. In any case, it was the consensus of the,*ADVANCE* Steering Committee that commercially available systems using dynamic information were still some time away from being available in the U.S.

market place and also that the communications platform established for *ADVANCE* was likely not to be a commercially viable option.

Given the changes described above, the *ADVANCE* Steering Committee requested a review of the deployment options. The review included the impact of deployment options on the goals of the Project. Three options were reviewed in detail:

- Controlled Wrapup - This involved stopping all further development on *ADVANCE* and documenting the results/design to date. This option was deleted from consideration as it was believed by all Parties involved that there were still significant findings to be made by continuing with *ADVANCE* at minimal additional cost.

- Targeted Deployment - This option involved a reduction in the level of development with a limited deployment of vehicles. Approximately thirty project test vehicles would be used with testing being done by project staff, paid drivers and some previously recruited drivers. No in-vehicle units would be installed in private vehicles. Testing would occur over a seven month period with all testing completed by the end of December 1995. A project evaluation would be performed based on a revised set of goals and objectives. The total number of vehicles involved in supplying probe reports would approach seventy-five.

- Full Deployment - *ADVANCE* would continue on its planned path with further development being done on all subsystems. The final release schedule would have been maintained and up to three thousand in-vehicle units would have been installed for a period of up to two years. A full evaluation would have been done with project testing and data collection completed by early 1998. The analysis of data and evaluation report would be completed by December 1999. The significant funding requirements, the complexities involved and the lack of an obvious transition to a wider area of deployment were examined.

An analysis of these options was performed by the Project Team and the Technical Advisory Committee. The recommendation was that the Targeted Deployment option would best serve the needs of the project partners and the ITS industry as a whole. It was believed that a significant portion of the original goals and objectives could be met under a Targeted Deployment. This option still allowed for testing of an in-vehicle dynamic route guidance system at a significantly lower budget. Further, it expedited the sharing of state-of-the-practice results associated with the operational test. The Targeted Deployment was realized with the finalization of the configuration and integration of the four subsystems in late spring of 1995.

3.0 OVERALL EVALUATION PROGRAM

Deployment of new ITS technology demands verification that the purposes of the deployment have been achieved and that results of development and deployment have been commensurate with resources expended. The original planning for the *ADVANCE* deployment called for compilation of a large evaluation database throughout the expected three-year project lifetime. This would have provided the basis for broadly informative and reliable tests of the various features of the project's systems and subsystems with respect to their capability to perform their stipulated missions.

With the Targeted Deployment, plans for assembling an evaluation database changed only in scope. Although sample sizes and the number of data points were significantly diminished, it was still possible to collect adequate data to inform others about expected performance of and user response to similar system deployments. This philosophy motivated the developers of the *ADVANCE* evaluation plan, in concert with the evaluators, to devote considerable attention to defining the objectives and resources necessary to conduct useful tests, then to deriving a feasible schedule under known time constraints for conducting all needed activities in the field and at the TIC itself. As applicable, the evaluation test plans that were ultimately prepared identified:

1) the data to be collected and the procedure for its collection,
2) the hypotheses about system performance to be tested using these data,
3) the chronological window(s) (calendar dates) during which data would be collected, and
4) the resources required to perform the tests.

Upon finalization of these plans, it was found that the test schedule included virtually no slack with respect to any of the resource allocations if there was to be any hope of completing all tests prior to the scheduled complete de-installation of the in-vehicle navigation units by the end of the calendar year. Evaluation testing of the subsystems commenced in June 1995 and terminated in December 1995.

3.1 Organizational Structure

The Federal Highway Administration (FHWA) was responsible for evaluation, including preparation and implementation of an evaluation plan. In April, 1995, the FHWA requested that Booz.Allen & Hamilton (Booz.Allen) assume responsibilities as the Evaluation Manager for the *ADVANCE* Targeted Deployment, until Argonne National Laboratory (ANL) could be brought under contract. Booz.Allen personnel examined the system design and conducted interviews with the *ADVANCE* project Parties in order to assess the revised project goals with respect to National IVHS Program goals, Illinois Department of Transportation (IDOT) requirements, and other *ADVANCE* Parties' interests. Booz. Allen worked with the Northwestern University Transportation Center (NUTC) , the

University of Illinois at Chicago Urban Transportation Center (UIC/UTC) and De Leuw, Cather & Company to develop evaluation test plans. Additionally, they documented the evaluation roles and responsibilities for the *ADVANCE* Parties. The University of Iowa was also engaged through Science Applications International Corporation (SAIC) to perform a safety evaluation of the MNA.

The following roles and responsibilities were identified in order to maintain continuity in the evaluation process and keep the evaluation efforts focused on the goals of the Targeted Deployment.

3.1.1 Evaluation Manager

ANL was responsible for implementing the evaluation plan and creating a publicly-accessible information source about the project. As Evaluation Manager, ANL maintained a presence at the *ADVANCE* Project Office through the evaluation field testing and supported the following activities:

- TIC operation and configuration control
- Vehicle scheduling and distribution for individual test evaluators
- Daily status meeting, including weekly Project Office status meetings
- Interactions between TIC operator, evaluator's test director, and the Project Office during daily test operations
- Daily test preparation activities, including definition and adherence to test plan
- Data collection
- Monitor vehicle reporting during test activities.

ANL designed and maintained a public report database consistent with the desires of the *ADVANCE* Project Office and information requirements specified in test plans. ANL also managed and maintained individual evaluator data accounts and all test and evaluation data was archived to support evaluator and Project Office requirements.

ANL coordinated and supported the development and distribution of survey instruments. This included the development and presentation of training materials for the Familiar Drivers Study. Training materials were prepared to familiarize drivers with MNA capabilities and operational characteristics. ANL maintained all evaluation test and report schedules, and vehicle utilization schedule.

3.1.2 Project Office

Project Office staff was composed of IDOT and De Leuw, Cather personnel. In conjunction with project management tasks, Project Office personnel verified driver credentials, assigned vehicles, and distributed vehicle data sheets and keys. Hired and volunteer drivers were familiarized with standard operating procedures and supported Familiar Driver Study participant notification, scheduling, and training. Project Office staff maintained an operational fleet and coordinated unscheduled and scheduled maintenance activities between evaluation testing and Project Office special needs.

Project Office staff also provided TIC operators who assisted the Evaluation Manager in reading memory card files and transferring data to Evaluation Manager's TIC account. Installed in each MNA, these memory cards recorded all links traversed by the probe vehicles. TIC operators also performed daily and weekly backups on TIC in accordance with standard operating procedures. Project Office personnel were responsible for authorizing configuration control and system modification procedures. Recommendations were provided to the Evaluation Manager for all hardware and software engineering change requests.

3.1.3 Evaluators

System evaluators, NUTC, UIC/UTC, De Leuw, Cather & Company, and the University of Iowa, conducted data collection in adherence to test plans. Evaluators designed data collection forms and coordinated database requirements and archiving procedures with Evaluation Manager. Data analysis progress and data quality control information was coordinated with the Evaluation Manager. Evaluators also provided applicable daily, weekly, interim, draft and final reports in accordance with the evaluation schedule.

The Evaluators were responsible for recruiting, hiring, and compensating hired drivers and were responsible for ensuring that the appropriate number of hired drivers arrive, with proper identification, at the Project Office for daily test training.

The Evaluators provided test directors to:

- Train drivers on daily test procedures
- Provide appropriatelogs to drivers, and observers when appropriate, and advise drivers of applicable protocols with respect to test execution
- Manage data collection, either in field or at TIC, depending on Evaluator requirements
- Maintain communication between TIC and designated test personnel
- Plan, implement, and coordinate data collection
- Inform Evaluation Manager and TIC Operator of daily test procedures, including designated routes, coordination procedures, etc.
- Maintain detailed test event log
- Coordinate vehicle replacement or test plan or test scenario deviations in the event of vehicle malfuctions and other anomalies.

3.2 Insights and Achievements Test Plan

The purpose of Insights and Achievements is to develop a summary of lessons learned which could be applicable to other project deployments and operational tests. It is an attempt to try to answer the questions: "If you had to do it over again, what would you do differently? What would you do the same? What have you learned that you think would be useful to others?"

The various authors have documented what was learned during this project through a series of white papers. Topics were proposed by the Technical Advisory Committee (TAC) for endorsement by the Evaluation Manager, Project Manager, FHWA and Steering Committee. Once *each* specific topic was approved by the Steering Committee, a detailed plan was developed to enable production of the each white paper. Once this detailed plan was approved by the Evaluation Manager, the white paper authors were given approval to commence writing. Draft and final white papers were presented to the Evaluation Manager and Steering Committee for review and comment.

The *ADVANCE* Insights and Achievements White Paper Topics are as follows:

a. Contractual and Management Challenges of the *ADVANCE* Project
b. Development of the RF Subsystem for *ADVANCE*
c. System Integration Challenges in Developing *ADVANCE*
d. Field Data Collection Activities and Experiences in Suppport of the Formal Evaluation of the *ADVANCE* Targeted Deployment
e. Technical Challenges in Developing *ADVANCE*
f. Estimating Environmental Effects of a Probe Vehicle-Supplemented Traffic Information System with Lessons Learned from the *ADVANCE* Targeted Deployment
g. Recruitment of Volunteer Drivers for *ADVANCE,* Summary of Procedures followed and Lessons Learned
h. Probes and Detectors: Experiences Gained from the *ADVANCE* Targeted Deployment
i. Institutional Issues
j. Implementation of Algorithms for *ADVANCE*
k. Targeted Deployment
1. *ADVANCE* Safety Evaluation Study

Section 4 summarizes the methodology and findings of each paper which are presented, in their entirety, in their respective Appendix.

4.0 INSIGHTS AND ACHIEVEMENTS

The methodology and findings of each Insights and Achievements paper are summarized in the following subsections. Each paper is presented, in entirety, in their respective Appendix.

4.1 Contractual and Management Challenges, 8465a

The *ADVANCE* Project is a prime example of a public-private partnership. Such partnerships seek to combine the capabilities and benefits of public agencies and private organizations, both for-profit and not-for-profit, in advancing their jointly-held and individual objectives. The *ADVANCE* Operational Test was, at its inception, proposed to be the largest field test of dynamic route guidance in the United States. The scope of the test and the public-private nature of *ADVANCE* was a challenge to the normal contracting and operating procedures of all participants.

This paper covers the development of the *ADVANCE* concept as well as the contractual arrangements used in the project. It provides insights on the unique nature of *ADVANCE* and the methods used to manage the project.

The paper is organized in the following way. First, the origins and background of the project and the apparent objectives of the participants are reviewed. Next, the negotiation of participation and agreement issues is discussed. Finally, the paper describes a number of the unique institutional arrangements and outcomes. Cost sharing issues, for example, were resolved by establishing a more comprehensive accounting system. Issues such as project management methods, intellectual property rights, and liability are also addressed.

The scope of the test and the public-private nature of *ADVANCE* was a challenge to the normal contracting and operating procedures of all participants.

4.2 Development of the RF Subsystem, 8465b

The development of the RF subsystem for *ADVANCE* met the challenges of matching existing communications technology with new concepts from the ITS arena. The RF communications system provided the capability for data transfers between the probe vehicles and the TIC. The inbound direction to the TIC consisted primarily of travel time reports. The outbound direction primarily supported TIC informational broadcasts to all probe vehicles of updated link travel times. This report documents the development of the *ADVANCE* RF subsystem, the alternatives and subsequent challenges encountered, and the lessons learned.

On the surface, providing two-way wireless communications between mobile users and the Traffic Information Center (TIC) meant that a variety of options could be used. The intent to focus on proven technology narrowed the field, however new approaches within the ITS world were also explored. Once the desired option was selected, the challenges lying within it presented unanticipated problems that needed reasonable solutions for all related subtasks to proceed. The results are expected to offer valuable insight to future developers of RF communications for ITS applications.

The experiences of the RF communications system development for *ADVANCE* proved very valuable. Defining factors include the RF spectrum, available technology, messaging structure, and related hardware. It may be necessary that future systems support an iterative process, as happened in *ADVANCE,* where hardware and the RF spectrum are continuously re-evaluated to zero in on a suitable RF transmission product that works within an available band. Furthermore, the desire for high speed data radio transmission cannot ignore the capability of the terminal equipment and its applications. Careful coordination is required between communications and applications to ensure the terminal equipment will accommodate a high data rate. Finally, market potential for the technology and the product is critical to successful deployment and consumer acceptance. The partnership between public and private enterprise has to meet varying goals, profitability being a key factor for private enterprise. A functional, successful implementation must consider the ability of the consumer to afford this technology.

In their present stales, the 19.2 kbps RD-LAP system and the 64 lbps MIRS system most likely would be successful today for a large scale deployment, replacing the 4800 bps system used in this project.

4.3 System Integration Challenges, 8465c

This paper focuses on the integration aspects of the *ADVANCE* system. Relevant system integration issues and challenges were captured from project meeting minutes, memos, discussions with *ADVANCE* personnel and author recollections. The findings have been separated into five categories: General, MNA, TIC, TRF, and COM.

The majority of the findings relate to the concept of how the system integration team was able to increase communication between the system, subsystem and component designers, developers and integrators. Also, discussed is the importance of communication within each organization and the need to remain open and accessible with respect to transfers of information. The findings also show the need for thorough documentation to be developed at each stage of the project. To ease the burden on the integration process, the use of releases is a very effective concept. However, in order for it to work properly, it must remain on schedule. The findings relate the difficulties in managing subsystems at different release levels and the need for thorough testing by designers and developers prior to releasing subsystems to integrators. The system integration testing team was challenged with managing the different subsystem releases and their respective sets of requirements and capabilities.

In summary, the recommendations for future similar systems are:

- Provide a means for effective communication between designers, developers and integrators.
- Monitor the communication and provide means to allow for feedback.
- Require thorough documentation at all stages of the Project.
- Perform system integration testing for each release. Avoid, if possible, testing mixed releases.
- Pretesting of subsystems and components before integration testing is essential.
- Tools to aid integration testing should be designed as part of the overall system design,
- Deficiencies uncovered during testing should be tracked to ensure proper and timely resolution.

4.4 Field Data Collection Activities, 8465d

This paper documents how the evaluators and other parties integrally involved with the *ADVANCE* Targeted Deployment implemented and maintained an evaluation data collection effort consistent with plan specifications, despite encountering numerous obstacles during the testing period. Operational challenges were encountered (and overcome) in attempting to meet critical test requirements, including:

- Availability and deployment of paid drivers.
- Availability of project vehicles.
- Route and staging area specifications.
- Real-time data retrieval tracking.
- Provision for unusual occurrences.
- Data capture and archiving.
- Survey sampling adequacy.

Key findings in meeting these challenges were:

- Hiring of paid drivers for specific tests should be done based on conduct of an interview no later than a few weeks before the start of the test. Other means of recruitment evaluation are likely to prove less satisfactory.

- The pre-test agreement signed by "volunteer" drivers should provide for an explicit reward for timely completion of or penalty for non-response to survey instruments; otherwise, it is almost certain that the post-test survey response rate will fall short of 100 percent of target.

- Insurance coverage should be given the highest priority for resolution before field testing protocols and schedules are finalized. In particular, persons hired for temporary driving jobs need to be provided with specific insurance coverage to limit their risks.

- If vehicle staging areas in residential areas are used, it is not likely that all potential objections from neighboring residents can be anticipated and allayed in advance. Nevertheless, prior clearance with local law enforcement and directly-affected institutions (school, shopping areas) is essential for both logistical and diplomatic purposes.

- Written logs should be maintained to document unusual events during tests: paper trails are vital to attempting after-the-fact diagnoses of operational problems that resulted in lost or corrupted data. Where electronic data collection is used, a backup automatic data retrieval system should be in place for all critical field testing.

4.5 Technical Challenges, 8465e

In developing *ADVANCE*, many lessons were learned and challenges overcome. This report documents the technical challenges that were faced and the lessons learned that could be used by others that are planning to develop similar systems.

Key findings of the report include the following:

- Retrofitting of a display unit near the driver in a safe location is difficult due to airbag deployment zones.

- The design of similar systems should be a "bottoms up" approach wherein functionality is added as the capacity of the hardware and the project schedule are defined.

- The technologies used for the in-vehicle unit, although well developed, need further refinement to ensure performance under all climatic conditions.

- When testing the in-vehicle unit, it was found very helpful to have diagnostic tools which captured incoming and outgoing data streams.

- The lack of availability of proprietary information for the in-vehicle unit affected the ability of the system integrators to fully test the system and also slowed the integration process.

- Rapid prototyping of similar systems to obtain user feedback on the TIC interface during the design process is recommended.

- Where a developer does not write his/her own code, it should be a requirement that they check the code with the coder after it is written to ensure the design has been interpreted correctly.

Despite the challenges noted above and the lessons learned, it is important to note that a fully functioning dynamic in-vehicle navigation system was successfully developed and deployed.

4.6 Estimating Environmental Effects, 8465f

This paper is intended to link some of the specific test experiences with the existing literature on ITS effects and thereby draw inferences about how driver behavior and response under an *ADVANCE* type of ATIS deployment would affect the vehicular emission results of such deployment and, by extension, of other ATIS concepts.

Findings are as follows:

1) Results of tests involving drivers familiar with the *ADVANCE* network suggest that drivers with good network knowledge and no constraints on the use of local streets often believed they could find faster routes than those offered by the *ADVANCE* system. This in turn suggests that it may be possible to generate more net time savings if route planning constraints are relaxed and the number of candidate routing links thus increased.

2) It appears that no driver would completely relinquish navigational control to a real-time ATIS navigation capability so long as known limitations or impairments of network data remain in the navigation data base. Policy considerations at the present time preclude the removal of all such limitations, and this minimizes the extent to which any emission benefit of this ATIS concept can be measured or attributed.

3) Nothing revealed by the *ADVANCE* field tests refutes the conclusion appearing in ATIS research literature that, during periods of recurring congestion, those who experience the highest costs from congestion will have found ways to alter their routes or timing, and those who are more willing to bear congestion costs will stay on congested roads. The *ADVANCE* user population

could not be reliably separated into these two groups, so no inference can be offered about the likely broader driver population split between congestion rejecters and congestion acceptors.

4) Reliable real-time information during periods of *nonrecurring* congestion, the provision of which is a key component of *ADVANCE* and similar ATIS deployments, appears to possess a high implicit value for virtually *all* drivers.

5) It follows that, in order to maximize the probability that real congestion reduction and emissions improvement will result from an ATIS deployment, the system should have the following features:
   a) accurate information on link traffic conditions available with the shortest possible delay in communicating it to ATIS users;
   b) an accurate, reliable route planner with few if any limitations on link/route combinations; and
   c) a convincing argument to the would-be purchaser of ATIS services that real, measurable benefits will accrue to him/her.

   The *road network* in which this system is to operate should have alternative route options that are faster and not too much longer (significantly greater length can mean higher emissions) than the original route of choice, and which generally have excess capacity (mitigating the problem of diverted congestion).

6) Another way of stating point 5c (above) is that the gap between system *potential* and actual system performance must be closed before the confidence of prospective ATIS users can be won sufficiently to make them acquire the system and act consistently on ATIS guidance.

4.7 Recruitment of Volunteer Drivers, 8465g

The *ADVANCE* Project originally planned to engage 3,000-5,000 households in the "Familiar Driver" test of its in-vehicle dynamic route guidance system. The *ADVANCE* Targeted Deployment ultimately involved only 80 households and 127 drivers in the Familiar Driver test. These drivers were recruited using a reduced version of a process originally designed for the full-scale deployment. This paper provides an overview of *ADVANCE* recruitment procedures, their development and implementation. It is based on the series of technical documents produced in the design of recruitment procedures, screening instruments, participation agreements, as well as the experience and perspectives of some of the key actors in the *ADVANCE* recruitment process.

The lessons learned from this experience may be helpful to others engaged in the recruitment of volunteers to test new ITS technologies. Those lessons include the following:

- Recruitability studies using focus groups and surveys were useful in the design of experimental conditions and driver participation agreements.

- Free publicity in various forms was sufficient for attracting over four hundred applicants for the *ADVANCE* Targeted Deployment. A larger field test would almost certainly demand a specific solicitation effort, probably involving advertising, either paid or free.

- A substantial amount of free advertising could probably have been secured if required.

- More aggressive solicitation might have been required to include under-represented groups (e.g., women and older drivers).

- Evidence from the Targeted Deployment of *ADVANCE* suggests that application forms can be effective for screening drivers to meet specific criteria.

- Cooperation from the Illinois Secretary of State's office made it possible to check the driving record of *ADVANCE* applicants to screen out drivers with poor records.

- That only 4% of otherwise-eligible drivers were rejected because of poor driving records suggests that application forms and publicity about the project led to self-screening, so that those obviously ineligible did not submit applications. It is also possible that the screening criteria were not so stringent as to exclude many drivers.

- By balancing concern for *ADVANCE* Party liability against the interests of volunteer drivers, a fair and understandable driver participation agreement was crafted.

- Volunteer drivers were willing to accept reasonable responsibility for the in-vehicle equipnient and, in the case of the *ADVANCE* Targeted Deployment, for the vehicles themselves.

- Personalized, hands-on driver training in the test vehicles quickly prepared volunteers for safe and efficient use of the *ADVANCE* system.

- An efficient and responsive computer database for contact management is essential for a field test involving large numbers of volunteer drivers.

- Designing and overseeing the recruitment process through a group representing all participating parties in the field test may be cumbersome but is essential to accommodate all important interests in and constraints on the recruitment process.

- Implementing the recruitment process with a knowledgeable and efficient single-point-of-contact agency may serve the volunteers well and preserve the resources of the technical staff.

- Critical details, such as dealing with leased vehicles, implications for and requirements on drivers' insurance, use of vehicles by persons other than those signing participation agreements, etc., can take substantial time to negotiate but may become important in large experiments using volunteer drivers.

4.8 Probes and Detectors, 8465h

This paper presents key aspects of probes and detectors that the authors have learned through their participation in the design and evaluation phase of *ADVANCE.* Some of the early decisions made during *ADVANCE* design are revisited. For example, one such decision was to use default travel time estimates called static profiles. These estimates would be replaced by dynamic estimates only when the latter differed substantially from the former. This decision, which was made originally on the basis of RF capacity constraints, was controversial. However, it is clear now that this would have been a sound concept even if the was no RF capacity constraint. This experience also substantiates the great importance of static estimates as an initial basis for real-time systems.

Properties of probe observations that were learned through analysis are also discussed. The quality of travel time reports provided by probes was generally very accurate. Probe reports are not statistically independent. This implies that the simple statistical formulae often used in traffic engineering need to be reexamined because they are based on independence of observations. Another implication is that there is a severe diminishing marginal return in quality with respect to the level of deployment. This implies that not much improvement in quality of estimates will occur as the level of deployment rises. In other words, a very high level of market penetration is not needed for a probe based system to be effective. Finally, any procedure which uses probe information needs to recognize the inherent stochasticity of such information.

The experiences of the authors in attempting to convert detector information into travel time estimates is also addressed. Detectors were found to be fairly effective under low and moderate congestion. Detectors were not found to be of much value in high congestion situations unless the deployment of detectors is increased. A brief comparison of probes and detectors is also presented in this paper.

4.9 Institutional Issues, 8465i

This paper emphasizes specific institutional issues encountered and resolved in the performance of the *ADVANCE* operational test. The major institutional issues for *ADVANCE* related to the progression of an ITS technological development effort from concept to reality. These major issues include:

- Leadership changes that occurred among the *ADVANCE* Parties during the project.
- The delicate role that the Project Manager was placed in.
- Continuous involvement of legal and financial staffs from each of the Parties.
- Concerns about financial liability resulting from operation of the *ADVANCE* fleet.
- Procedures for fleet operation issues.
- Developing and executing comprehensive driver participation agreements.
- Providing sufficient information regarding project specifics to each driver.
- Providing adequate assistance for malfunctioning vehicles or navigational equipment.
- Establishing adequate procedures to resolve procurement/audit issues with private sector participants.

At times, the institutional issues encountered in *ADVANCE* caused minor delays in the Project because they caused uncertainty in completing administrative responsibilities according to schedule. However, despite these obstacles, the Parties made the commitment to work together to satisfactorily complete the goals and objectives established for the Project. Equally important, the institutional issues identified and resolved in *ADVANCE* will serve as valuable lessons for future ITS projects.

4.10 Implementation of Algorithms, 8465j

Development and implementation of new traffic analysis algorithms in a real world application environment with a fixed time schedule requires coordination and collaboration among algorithm developers, implementation programmers, developers and installers of the technology to be used for data collection and communication and the operators of the implemented system. Effective management of this process requires a carefully structured work program which includes adequate time for completion of all required tasks and which recognizes interdependencies among tasks. This work program must be flexible enough to respond to changes inherent in the development of technology or algorithms.

A further issue in the development, estimation, validation and refinement of algorithms is the availability of data to support these activities. Such data are required early in the algorithm development process. If such data are not available from. field data collection, simulation data can be used to support initial development. However, field data are required for final validation and refinement. If the collection of such data requires use of the implementation system, as in the case of *ADVANCE* the order of development of system components should include provisions for such data collection after the implementation of all operational systems, at least on a prototype basis, and time to use such data for algorithm validation and refinement before final implementation.

This paper describes the procedures undertaken to maintain coordination among developers, program implementors and operators and describes implementation problems which arose and their treatment. It also describes the use of simulation data for initial development and highlights the importance of field data for final refinement and validation.

4.11 Targeted Deployment, 8465k

The purpose of this report is to document the development process and experience of the *ADVANCE* project, in particular as relates to ultimate deployment of this operational field test. This paper examines the issues and options considered in the decision to redirect the originally planned deployment of 3,000 in-vehicle dynamic route guidance systems to a deployment of less than 100 units.

After analysis of current conditions, it was agreed that a significant portion of the original goals and objectives could be met under a Targeted Deployment. It was decided that a Targeted Deployment would best serve the needs of the project partners and the ITS industry as a whole. This option allowed for limited testing of an in-vehicle dynamic route guidance system at a significantly lower budget. It expedited the sharing of state-of-the-practice results associated with the operational test.

Several very important conclusions and recommendations result from this review of Targeted Deployment issues encountered during *ADVANCE*. These recommendations for future ITS projects include the following:

- *ADVANCE* was able to achieve its basic goals at significant savings in time and money by adopting the Targeted Deployment strategy.
- All project management and Steering Committees should remain vigilant for changed conditions from those in existence at the inception of any large scale, long term field test.
- Redirection of efforts may well have an overall benefit, even though specific targets of development are temporarily abandoned for pursuance by future projects.
- Expediting the dissemination of current findings to other developers nationwide may be more valuable than delaying this information sharing until a more conclusive evaluation is achieved / accomplished.

The ADVANCE success in achieving almost every one of its original goals and the wealth of data collected in this more limited effort are enumerated.

4.12 Safety, 84651

The purpose of the Safety Evaluation of the *ADVANCE* Project was to assess whether drivers drive and navigate more or less safely with the MNA than without it. The project also intended to increases the body of scientific knowledge on how drivers operate a vehicle while navigating. In addition to evaluating safety, detailed data regarding driver performance was collected. Whereas, in the absence of accidents, the relationship between driving performance and safety is not clearly defined, it is assumed that such a relationship exists, and, therefore, another goal of this study was to extend the understanding of the relationship.

The study examined the effects of four navigation scenarios on driving and navigation performance. The navigation scenarios were: (1) MNA with voice supplement, (2) MNA without voice supplement, (3) a paper map, and (4) a paper direction list. The latter two scenarios served as control conditions. In addition to the four navigation scenarios, the study examined the influence of age and experience with the MNA on driving performance and navigation. Sixty drivers split by age and gender drove each of the four different navigation conditions.

Analysis of the data suggests that no element of the MNA system is particularly hazardous to driving safety. This conclusion is supported up by several findings. First, no accidents occurred while navigating with the MNA, even though two-thirds of the subjects had no prior experience using the system, and half of those inexperienced drivers were over the age of 65. However, while the number of accidents is probably the most valid indicator of driving safety, it is not the most robust measure, given the levels of exposure afforded in this study. Therefore the occurrence of near misses was also considered as an indicator of system safety. Second, whereas there were occurrences of near misses and driver errors (with a hazard present in the driving environment) while the MNA was being used, the number of these occurrences was either less than or equal to the number of occurrences with the paper map and direction list conditions that served as control baselines.

One of the primary lessons learned on this project is related to auditory message presentation. In this study no performance benefit was observed to result from the addition of a voice supplement to the visual MNA display. This finding differs from a previous finding in the TravTek field operational test where voice supplement was observed to increase driving and navigation performance. Thus it appears that the mere addition of a voice does not necessarily guarantee enhanced driver performance. Message content and timing differences between the TravTek and MNA voice supplements are probably the reason for the difference in results between the two studies. Future

ATIS navigation system designers should explore the effects of voice message content and their relationship to driver performance, safety, and driver preference. More context-specific voice information may provide drivers with increased confidence and situation awareness and increase safety. As the computing power for in-vehicle navigation technologies increases, so will the number of sophisticated real -time options. Additionally, what is clear from this study and TravTek is that the turn-by-turn interface used for both systems yields equal or better driver performance than paper maps. This is an important result to pass on the future designers who may be considering alternative ATIS display designs.

The primary contribution to the ITS knowledge base for this study has been an increase in the general pool of data and knowledge about how drivers interact with both turn-by-turn graphical guidance displays and conventional navigation methods. The knowledge includes general driver performance data, eye glance behaviors, subjective preference measures, and a database of the types of errors committed. Additionally, new data acquisition and reduction methods were developed that will carry forward to future studies.

5.0 CONCLUSION

5.1 Overall Findings

Issues of technology, liability, intellectual and property rights, project management styles, and desired project outcomes routinely arose and were resolved during the *ADVANCE* Project. There were many lessons from the *ADVANCE* operational test. The primary lesson learned was the importance of a continuing, honest appraisal by the Parties involved in the Project of the viability of the operational test. Successful entities are constantly monitoring market conditions, technology, and opportunities to gauge project and product viability. *ADVANCE* was successful in following a similar course in reviewing and updating its direction based on changing conditions. The interaction among the Parties in reviewing options as the Project proceeded was a model for future efforts. Other key points are listed as follows:

- The scope of the test and the public-private nature of *ADVANCE* was a challenge to the normal contracting and operating procedures of all participants.
- The development of the RF subsystem for *ADVANCE* met the challenges of matching existing communications technology with new concepts from the ITS arena.
- Communication within each organization and the need to remain open and accessible with respect to transfers of information between organizations is of extreme importance.
- To ease the burden on the integration process, the use of releases is a very effective concept. However, in order for it to function properly, work must remain on schedule.
- Evaluators and other parties integrally involved with the *ADVANCE* Targeted Deployment implemented and maintained an evaluation data collection effort consistent with plan specifications, despite encountering numerous obstacles during the testing period.
- The design of similar systems should be a “bottoms up" approach wherein functionality is added as the capacity of the hardware and the project schedule are defined.
- Rapid prototyping of similar systems to obtain user feedback on the TIC interface during the design process is recommended.
- The gap between system potential and actual system performance must be closed before the confidence of prospective ATIS users can be won sufficiently to make them acquire the system and act consistently on ATIS guidance.
- The travel time reports provided by probes was generally very accurate.
- The density of probes need not be very high for a probe based system to be effective.
- Detectors are fairly effective under low and moderate congestion, but are not of much value in high congestion situations unless the deployment of detectors is increased.

- The institutional issues encountered in *ADVANCE* caused minor delays in the Project because they caused uncertainty in completing administrative responsibilities according to schedule.
- Development and implementation of new traffic analysis algorithms in a real world application environment with a fixed time schedule requires coordination and collaboration among algorithm developers, implementation programmers, developers and installers of the technology to be used for data collection and communication, and the operators of the implemented system.
- All project management and Steering Committees should remain vigilant for changed conditions from those in existence at the inception of any large scale, long term field test.
- Redirection of efforts may well have an overall benefit, even though specific targets of development are temporarily abandoned for pursuance by future projects.
- Expediting the dissemination of current findings to other developers nationwide may be more valuable than delaying this information sharing until a more conclusive evaluation is achieved / accomplished.
- The *ADVANCE* success in achieving most of its original goals and the wealth of data collected in this more limited effort are enumerated as a testament to the decision to implement the Targeted Deployment.
- The *ADVANCE* MNA interface proved to have no negative safety impacts, however, because no significant performance benefit was observed to result from the *ADVANCE* voice supplement in contrast to that of TravTek, future ATIS designers should explore the effects of voice message content and their relationship to driver performance, safety and driver preference.

The dynamic route guidance concept, which was central to *ADVANCE*, was tested, the infrastructure developed was transitioned to support a broader range of ITS deployments, and the multi-state corridor activities were supported and given a more central focus. The public and private participants in *ADVANCE* were provided with significant new information to continue their ITS deployment pursuits. Participants have agreed that the overall experience was challenging and productive: a positive as well as a pioneering example of public/private partnerships to develop state-of-the-art transportation systems.

5.2 Future Directions

With Targeted Deployment *of ADVANCE* dynamic guidance equipped vehicles came the realization that the Traffic Information Center was a resource which is the heart of information sharing efforts. The Traffic Information Center was the data gathering and processing hub of *ADVANCE* and the wide variety of data sources which were part of *ADVANCE* continued to be available after the dynamic guidance tests were completed. With the Gary-Chicago-Milwaukee Priority Corridor

Initiative solidly underway by the end of 1995, the continued development of the TIC resource as a prototype for a three-state corridor transportation information center became extremely beneficial.

Although efforts to integrate information sources had always been envisioned in *ADVANCE,* the Targeted Deployment provided a significant opportunity to transition to the Corridor Transportation Information Center. In the period beginning January 1996, the *ADVANCE* Corridor Transportation Information Center (C-TIC) was developed to handle not only the *ADVANCE* database but also real-time travel information from a broad multi-state spectrum of interests. The development was done in coordination with the Gary-Chicago-Milwaukee Priority Corridor initiative and includes an advisory committee with a multi-state and multi-modal constituency.

The *ADVANCE* Corridor Transportation Information Center is expanding beyond the *ADVANCE* test area to include expressways and major arterials throughout the Gary-Chicago-Milwaukee Corridor. This Corridor Transportation Information Center includes, an electronic linkage to share information from the SSI weather infonnation system, the Illinois DOT Traffic Systems Center, the Wisconsin MONITOR System, the Illinois DOT Communications Center, Northwest Central Dispatch, cellular “999, selected closed loop traffic signal systems and the prototype Illinois State Toll Highway Authority Electronic Toll Collection (ETC) system. An initial geographic area including Cook, Lake and DuPage counties has been expanded to include other states or regions as the systems become more mature. Transit information, beginning with incidents and delays, will also be provided. The prototype center is envisioned to be operational late in 1996. Expansion to include information from Indiana’s Borman Expressway initiative will follow, along with expansion to a broader set of public and private sector participants. The practical architecture is now being demonstrated and a full deployment scenario is being reviewed under the GCM Multi-Modal Traveler Information System effort.

The vision for the Corridor Transportation Information Center provides a system which could be accessed by a wide variety of transportation and communication interests who would share information in common formats and provide operations and safety information. Initially travel time information on selected links, construction and maintenance lane closures, and anecdotal reports of incidents will be provided on the Internet. It is anticipated that expressway travel times, lane closures and incident reports will be handled electronically by the end of 1996.

The C-TIC is in the process of being further developed in accordance with the national architecture recommendations into a fully functional corridor-wide program. The prime data providers into the system are the transportation and enforcement agencies who have responsibility for the Gary-Chicago-Milwaukee area systems. With the planned implementation, the prime beneficiaries would be the aforementioned providers plus the public who will then have access to the improved traffic and transit information. Radio and TV would also be given access. The information would be available to ITS developers and users to support not only in-vehicle guidance, but also a wide range of information concepts including personalized trip planning, providing transportation advisories through personal communication devices and general distribution through mechanisms such as kiosks and television. The C-TIC is providing significant opportunities for testing and enhancing national architecture and protocol efforts. The GCM Corridor Coalition has recently indicated that it will work with Oak Ridge National Laboratory to test the ITS Datum and Location Referencing Message Specifications. This work will serve as a national test of the ability to combine location specific information from a wide variety of geographic referencing databases. The corridor has also adopted the National Transportation Communication and Information Protocol (NTCIP).

APPENDIX A

CONTRACTUAL AND MANAGEMENT CHALLENGES OF THE *ADVANCE* PROJECT

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CONTRACTUAL AND MANAGEMENT CHALLENGES OF THE *ADVANCE* PROJECT

EXECUTIVE SUMMARY

The ***ADVANCE*** Project is a prime example of a public-private partnership. Such partnerships seek to combine the capabilities and benefits of public agencies and private organizations, both for-profit and not-for-profit, in advancing their jointly-held and individual objectives. The *ADVANCE* Operational Test was, at its inception, proposed to be the largest field test of dynamic route guidance in the United States. The scope of the test and the public-private nature of *ADVANCE* was a challenge to the normal contracting and operating procedures of all participants.

This paper covers the development of the *ADVANCE* concept as well as the contractual arrangements used in the project. It provides insights on the unique nature of *ADVANCE* and the methods used to manage the project.

The paper is organized in the following way. First, the origins and background of the project and the apparent objectives of the participants are reviewed. Next, the negotiation of participation and agreement issues is discussed. Finally, the paper describes a number of the unique institutional arrangements and outcomes. Cost sharing issues, for example, were resolved by establishing a more comprehensive accounting system. Issues such as project management methods, intellectual property rights, and liability are also addressed.

The scope of the test and the public-private nature of *ADVANCE* was a challenge to the normal contracting and operating procedures of all participants.

CONTRACTUAL AND MANAGEMENT CHALLENGES OF THE *ADVANCE* PROJECT

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1.0 INTRODUCTION

1.1 Overview

The *ADVANCE* Project is an operational field test of an Advanced Traveler Information System (ATIS) undertaken with the support of the Federal Highway Administration (FHWA) as one element of its Intelligent Transportation System (ITS) program. Many of the operational field tests involve both public agencies and private organizations, including entities from the corporate, academic and consulting sectors.

The *ADVANCE* Project is representative of this mix of public and private participants. The public agencies are the Illinois Department of Transportation (IDOT) as well as FHWA. The principal corporate entity in the Project is Motorola, Inc.; moreover, many corporations participated at a lower level, including several automobile manufacturers, both domestic and foreign, a major computer hardware vendor, several software vendors, and other suppliers of ITS-related components. The principal academic participants are Northwestern University and the University of Illinois at Chicago, under the aegis of the Illinois Universities Transportation Research Consortium (IUTRC), a not-for-profit organization operated by the principal transportation research universities in Illinois. The fifth principal participant is the American Automobile Association, in conjunction with the Chicago Motor Club, which joined the project near the end of its design phase. DeLeuw, Cather & Company is the systems integration and project management consultant and Argonne National Laboratory is the evaluation manager.

The *ADVANCE* Project, therefore, is a primary example of *a public-private partnership*. Such partnerships seek to combine the capabilities and benefits of public agencies and private organizations, both for-profit and not-for-profit, in advancing their jointly-held and individual objectives. The *ADVANCE* Operational Test was at its inception proposed to be the largest field test of dynamic route guidance in the United States. The scope of the test and the public-private nature of *ADVANCE* was a challenge to the normal contracting and operating procedures of all participants.

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1.2 Authors

Contributing authors are:

David Boyce - Director, Urban Transportation Center, University of Illinois at Chicago

Dr. Boyce was an early advocate of the *ADVANCE* concept. He was responsible for the coordination of university efforts for the university consortium as well as significant portions of traffic and system design and evaluation.

Paul Dowell - Motorola Manager for ADVANCE

Mr. Dowel1 was responsible for coordination and delivery of Motorola's portions of the project.

Joseph Ligas - ADVANCE Project Manager

Mr. Ligas was responsible for the overall coordination and implementation of *ADVANCE.* He is ITS Program Manager for the Illinois Department of Transportation.

1.3 Origins and Background

The genesis of the *ADVANCE* Project occurred at a meeting held at the District One Office of IDOT in March, 1989, but the impetus for this meeting occurred somewhat earlier. Motorola formed its Intelligent Vehicle Highway Systems (IVHS) Strategic Business Unit to enter the emerging field of intelligent vehicle highway systems in the fall of 1988. Its objective was to invest in this emerging technology in order to position itself as a major supplier of ITS equipment. Motorola's expertise and strong market share in communications, computer components and automotive electronics made ITS a natural arena for technology and new product development,

Faculty at two Illinois academic research centers had coincidentally identified ITS as a target for research and evaluation studies. David Boyce, newly appointed director of the Urban Transportation Center of the University of Illinois at Chicago, had been exploring Intelligent Vehicle Highway Systems (IVHS) and its impacts since 1986. He and Joseph Schofer Director of Research of the Transportation Center of Northwestern University, had described a research project related to ITS in a proposal to the U.S. Department of Transportation and IDOT. Moreover, Dr. Boyce was beginning to explore possible linkages with the private sector, including Motorola. Their objective was to undertake research on a variety of issues related to this emerging topic, as well as to raise research funds and involve graduate students in this research activity.

FHWA was a pioneer in the ITS field as early as the late 1960s with its initial efforts with an electronic route guidance system (ERGS). In response to staff and industry interest, as well as increasing activities in Europe and Japan, FHWA began formulating plans for an ITS program in the late 1980s. One example of this activity was the Mobility 2000 Workshop held in 1989 (TTI, 1990).

FHWA's objective was to lead the ITS technology development effort on behalf of the United States. A principal strategy in this effort was a program of operational field tests with substantial federal government funding. The implicit assumption of this program was that the technology development process was sufficiently advanced that operational tests of the technology were a meaningful next step.

Finally, IDOT had been a leader in the innovation and early deployment of traffic surveillance systems. It viewed the interest of Motorola and the university consortium as a sound basis for entering the emerging area of ITS. Moreover, the economic development potential for the State of Illinois of a major technology innovation was possible. As importantly, IDOT considered the proposed system a useful mechanism to obtain travel and incident information on its arterial roadways, and to manage this portion of its system in the same manner as it does its expressways.

The joint interests of Motorola, IUTRC and IDOT merged in March 1989, at a presentation by Motorola to IDOT. Motorola requested the assistance of IDOT in undertaking a field test of the dynamic navigation and route guidance system it was developing, recognizing that information on the status of the roadway system was necessary to the implementation and testing of its conceptual design. Motorola believed that traffic information was available for the entire highway system, whereas in fact, detailed data only existed for IDOT's expressways in the Chicago area, and not for the Illinois tollways, much less the arterial streets.

At this meeting, it was decided that IUTRC and Motorola jointly undertake a feasibility study of the conceptual design with partial funding from IDOT. A proposal was prepared and approved; the study was initiated in August, 1989.

The feasibility study for *ADVANCE* was performed jointly by IUTRC and Motorola. IUTRC's work was partially funded by IDOT and partially by the participating universities; Motorola funded the work of its own staff.

Five technical issues did emerge in the feasibility study:

1. the dynamic capabilities of the proposed route guidance system; that is, the use of current travel time information to plan and update routes;

2. the proposed sources of the dynamic travel time data, and their implications for a

two-way communications system;

3. the need to determine the number of equipped vehicles, or probes, to conduct an operational test;

4. a definition of the components of the system with regard to traffic engineering and network performance.

From the outset, the team believed that the route guidance system should be dynamic, a seemingly reasonable objective given that static systems were being tested in the United States by Etak and Delco, as well as General Motors Research Laboratories. Beacon-type dynamic systems were being implemented in Berlin (LISB) and Tokyo (CACS); in addition, the TravTek test was being designed for Orlando with modest dynamic capabilities.

What was not questioned concerning the dynamic system objective was the difficulty, and the time and cost requirements, for designing and implementing a large scale system from scratch.

In view of Motorola's strong qualifications with RF communications, and the apparent high cost of infrastructure for a beacon system, the former was agreed to as the solution to the dynamic data issue. The acceptance of this solution reflects some of the pragmatic discussions in the early portions of the project. In fact, the design of a cost effective RF communications system for *ADVANCE* became a major design challenge. (One that was met after significant effort,)

The adoption of the area wide design alternative led naturally to the question of how many equipped vehicles were needed to conduct the test over an arterial network. Members of the university team applied a sampling procedure to the results of a static route choice model to determine the frequency of link traversals in a prototype study area. The result was on the order of 3,000-4,000 vehicles operating in the network during congested periods of the day.

This estimate, accepted by the study participants, had major implications for the cost and design of the in-vehicle unit.

The final issue discussed here concerns the definition of the traffic and transportation network elements of the system during the feasibility study. These elements, which ultimately became known as the Traffic Related Functions (TRF) component, were only generally discussed in concept design of the feasibility study. Some of the elements of TRF which were included were: incident detection and near-term prediction of travel times. Only generally mentioned is the notion of data fusion. The use of a network model to prepare initial estimates of network travel times was not included. Each of these became major tasks in *ADVANCE*. In the case of data fusion, little information was available to begin this effort and significant efforts were required. In the case of preparing initial estimates of travel times, the use of a network flow model supplemented with a fatal flaw review done by operating staff resulted in an acceptable data base.

2.0 *ADVANCE AGREEMENT*

The feasibility study became the initial stage in the implementation of the project, a task to be completed in order that negotiations could begin on an agreement to proceed with the actual design work.

The final report on the feasibility study (Boyce, et al., 1990) was submitted in August, 1990. Shortly afterwards, a meeting was held concerning the next steps needed to implement the project. This meeting led to the preparation of an initial budget for the design phase, then estimated as 12--18 months, and set the stage for the negotiation of an agreement among the four participants (FHWA, IDOT, Motorola and IUTRC) to undertake the operational test.

The negotiation of the agreement began in November, 1990, and continued at the rate of about one meeting per month through March, 1991. A signing ceremony was initially scheduled for April, but occurred on July 9, 1991. The participants in the negotiations were FHWA representatives from the Washington, regional and state offices; the principal participants in the feasibility study from Motorola and IUTRC, and IDOT staff.

The principal issues considered in these negotiations go to the heart of the public-private partnership that was sought. They are the following:

1. objectives of the operational test and responsibilities of the parties including the need for a systems designer/architect;

2. governance and project management;

3. source of funding and cost sharing by the participants;

4. intellectual property rights;

5. liability for accidents occurring during the test.

These issues are now discussed in the order listed above, which corresponds to their order in the IVHS Agreement.

2.1 Objectives and Responsibilities

The project’s goals and objectives were addressed in the feasibility study and reviewed in these negotiations. They are broad, relatively far-sighted and noncontroversial. Government agencies were particularly interested in testing the effectiveness of using vehicles as probes and developing methods to establish cooperative programs with the private sector.

It became apparent early in the negotiations that legal and policy issues would be a major challenge to the project. As an example, the original drafts of the Agreement used the term *partners* to refer to the four main participants in the Project. At the request of legal staff, this term was changed to *parties.* The reason was that the government agencies could not enter into a formal partnership of the type defined in the Agreement. Although this terminology caused much semantic confusion, no substantive effect or change seemed to result.

The discussion of the responsibilities of the four parties began with a design review at Motorola in November, 1990. By this time, IUTRC had added a computer scientist to its team, who was qualified regarding the use of engineering work stations for real-time operations, as well as search methods for route planning in various applications. This design review raised for the first time the issue of the need for a systems engineer, also referred to as a systems architect. The issue was raised by Motorola's leadership. It was evident that Motorola desired its responsibility to be primarily related to in-vehicle and communications systems, but at the same time they wanted to insure that provision was made for the overall systems design.

The issue of systems design was addressed in procurement of a project management consultant, who ultimately added the role of systems design and integration.

The agreement assigned responsibilities to IUTRC which clarified its future role in the project. First, the design of the Traffic Information Center (TIC) was assigned to IUTRC. Second, incident detection was identified as part of this design, which was in effect the beginning of the TRF component. Third, additional responsibilities were assigned to IUTRC related to system design, in addition to evaluation. The primary responsibility for the preparation of the evaluation plan, and its implementation, was reserved for FHWA Since a primary motivation for IUTRC to participate in the operational test was its interest and expertise in evaluation, this issue became particularly delicate. In the end, the issue was resolved by assigning IUTRC responsibilities related to certain evaluation work plans and their conduct. This issue illustrates the difficulties of defining and accommodating the diverse objectives of the parties in a public-private partnership.

2.2 Governance and Project Management

Responsibility for project management was assigned to IDOT. In addition, a Steering Committee was defined with one representative from each party. The Steering Committee definition and functions were not controversial; it has functioned well. The structure of committees reporting to the Steering Committee evolved to provide a solid base for the *ADVANCE* efforts.

Project management functions are described only in terms of administration of contracts, Although there is no reference to contractors, it is implied that the contracts are with Motorola and IUTRC, as well as other participants. This provision occasionally placed IDOT in the position of being both the sponsor and manager of the project, as well as a participant in the technical design process.

2.3 Funding and Cost Sharing

The provision for project funding in the Agreement states that the estimated cost of $35 to $42 million (taken directly from the feasibility study) will be split 50% from federal sources, 25% from state sources and the remaining 25% from Motorola, the IUTRC and other private sources, Moreover, it was stated that the in-vehicle hardware funding would be divided equally among a) federal, b) state, and c) Motorola and other private sources.

The 50/25/25 division of funding for costs other than in-vehicle hardware was readily accepted by all parties. However, the negotiations lacked detail. The participants to these discussions generally understood that Motorola would pay for the design costs of its in-vehicle unit. It was never estimated, however, how large these costs might be, and therefore what part of the private cost share they might comprise. In addition, There was no detailed discussion as to how these costs would be accounted for and audited.

The initial agreement did not define cost share specified by party, and how much of its cost share could be provided by other sources. In other words, the 50/25/25 split was only discussed in terms of the entire project, and not as applying to individual contracts between IDOT and Motorola and IUTRC. The agreement also stated that support may be solicited by individual parties and applied in support of their responsibilities under the Agreement. What was unclear was how such support would be represented in the contract budgets involving Motorola and IUTRC.

The split of funding for the in-vehicle hardware was even more difficult. Since the cost of the equipment was estimated to be $14-$18 million, it was not feasible for Motorola to contribute this amount. An agreement wasreached to split the costs three ways. It was believed at that time that auto manufacturers would be involved in funding a portion of this expense. As the project moved towards implementation, this belief was tested and found to be excessively optimistic. It should be pointed out that auto manufacturers were strong supporters of *ADVANCE*, but not to the degree originally anticipated. As a result, the Agreement was revised to treat in-vehicle equipment in the same manner as all other project expenditures.

2.4 Intellectual Property Rights

The negotiation of intellectual property rights was a perplexing issue, in part because the representatives of the parties, other than Motorola, had little experience with such matters. Because this is an issue rife with misunderstanding, the provisions of the Agreement are quoted in some detail.

First, the Agreement defines PARTY intellectual property as copyrights, patents, trade secrets and any other form of information developed by a PARTY with its own funds. Such Party Intellectual Property remains the property of the party.

Second, and more important, the following section of the Agreement describes Intellectual Property Developed with Government Funding:

"In accordance with provisions of 35 USC 200--212, which gives non-profit organizations and industry the right to retain intellectual property rights covering technology developed with government funding, each PARTY shall own and retain all rights to its inventions, discoveries and works of authorship made or created with government funding (referred to below as "Government Funded Developments"), subject only to the following:

1. The federal government and the State of Illinois shall each have a royalty-free, non-exclusive, and irrevocable license under any patents and copyrights covering such Government Funded Developments to use, reproduce, publish, and to authorize others to use the Government Funded Developments on behalf of the federal government or the State of Illinois.

2. Each non-governmental PARTY shall have the right to use other Government Funded Developments only in connection with its work under this Agreement. Use shall be on a royalty-free basis.

3. Government Funded Developments that are made jointly by the non-government PARTIES shall be jointly owned by those PARTIES and shall be subject to all the conditions set forth in this paragraph.

4. A PARTY who makes an invention with government funding shall, within two years after reducing the invention to practice, either 1) make its election to retain title to the invention under 35 USC 202(c), or 2) publish the invention for the purpose of putting it in the public domain.

The federal legislation referred to above is the Bayh-Dole Act, (P.L. 96--517) passed in 1980, and amended in P.L. 98--620 in 1984. This law amended Title 35 USC by adding Chapter 18, Section 200--212. The law was a culmination of events since 1945 leading to the decision that the public is best served by a policy which encourages the utilization of inventions produced under federal funding and which promotes the participation of universities in the development and commercialization process. The legislation is implemented as OMB Circular A--124, subsequently codified as 37 CFR Part 401. Moreover, the Federal Acquisition Regulations (FAR) were amended in 1984 to assure that all R&D agencies would implement the Bayh-Dole Act.

Once the language drafted by FHWA was provided and reviewed by Motorola, IUTRC and its member universities, there was no controversy about these provisions of the Agreement during the negotiating period. Whatever disagreements took place occurred before an understanding of the law was obtained.

On occasions during the project, issues related to intellectual rights continued to emerge. But in fact, no specific instance occurred where the rights to any component was challenged by another party.

2.5 Liability

Because the design of the *ADVANCE* Project provided for placing route guidance systems in private vehicles, there was substantial concern about the liability of the parties in the event of accidents involving these vehicles. Other than providing for sensible procedures in screening drivers during the recruitment process, it was concluded that there were no workable mechanisms for limiting the liability of the parties. In the end, each party agreed, in effect, to be responsible for its own liability, and not to be liable to the other parties. As the project developed, these issues continued to be raised where parties were anxious to protect themselves from liability. In fact, no liability claim against any party resulting from the conduct of *ADVANCE* have been made through development and operation of the in-vehicle testing.

3.0 EXPERIENCE AND OUTCOMES

In this final section, comments are offered on the experience of the *ADVANCE* public-private partnership and the general outcomes of the Project from this perspective. These comments are organized in the following way:

1. the use of operational tests in technology development;
2. contractual and cost-sharing issues;
3. project management methods and their application in technology development;
4. project leadership and duration.

3.1 Technology Development Research

The initial development of the ITS program was envisioned as a convenient way for academic researchers to participate in the development of this emerging technology and to become involved in an ATIS operational test. Industrial research units, such as at Motorola and General Motors, also recognized that they could not undertake the development and testing of this technology without the involvement of a public agency. Unlike other sectors such as telecommunications, the road network is public infrastructure on which experiments cannot easily be conducted by a private organization. The need of an appropriate test bed for the use of private developers resulted in the creation of the *ADVANCE* operational test. The result, almost inevitably, is that research was conducted during the design process; for this reason, alternative solutions could not be explored as fully, and as objectively, as desirable.

Much of this has been corrected in recent years with a more directed research program for ITS. Efforts such as the System Architecture Development and the Ideas Program allow for dealing with development issues without the need for an operational tests in many areas.

In terms of managing the technology development effort, IDOT's contractual and project management role in *ADVANCE* placed it at best in an awkward position vis-a-vis the other parties, and at worst in a conflict of interest situation. On one hand, IDOT was purchasing contractor services, sometimes of a consulting nature, from the other parties. As contract manager, IDOT was also responsible for making and maintaining a schedule. On the other hand, as written in the Agreement, IDOT was one of four paties *jointly* participating in the design and implementation of a very complex system. The ultimate result meant policy issues being dealt with as a partnership and project management evolving to a client-contractor relationship with three private contractors:

Motorola; IUTRC; and the project management and systems integration consultant, DeLeuw, Cather & Company.

Whether this result would have been different using another institutional framework is unclear. Obviously, it is necessary to have a management function in such a project, and it is also desirable to hold to established schedules. At the same time, as noted above, *ADVANCE* has much in common with applied research, in addition to systems design.

Research often requires a creative process which is not conducted on a rigorous schedule, as much as managers would like to wish to the contrary. This is especially true of the conceptual stages of such a project. The experience of similar projects in completely different fields may provide useful insights to ITS in this regard.

3.2 Contractual and Cost Sharing Issues

In its role as contract manager, IDOT also had responsibility, jointly with FHWA, for administration of the cost-sharing agreement and for audits.

For the universities, provision of their cost share effectively means a modification of the usual approach to budget preparation. Universities routinely cost share on externally funded projects by contributing more faculty time than is stated on the project budget. Since faculty do not maintain time records under the requirements of OMB Circular A--95, they are generally not even aware of the amount of this cost-shared time. For *ADVANCE*, this additional time had to be explicitly built into their budgets, requiring a different way of budgeting. Moreover, if contributions of computer hardware and software were secured, these costs also had to be reflected in the budgets, whereas normally they would be simply regarded contributions in support of the university's educational and research programs.

These costs were not part of the initial budgets. Having learned to make these adjustments in procedures, the budgets would reflect an increased cost resulting in budget amendments. This procedure resulted in a fuller accounting of the actual research program costs than is generally provided. After the first year's learning experience, this new budgeting process proceeded smoothly.

Motorola faced an entirely different problem in contracting. The Motorola IVHS unit is not organized to accept contracts from a public agency which requires accounting for expenditures, followed by an audit. In contrast, Motorola conducts its business on the basis of purchase orders for equipment and services at stated prices. Since Motorola desired to accept contracts from IDOT for its responsibilities pertaining to portions of design of communication systems, it needed to find a way to account for its contract and cost sharing expenditures and to be audited on them. The solution was to establish a more comprehensive accounting system within its IVHS unit for design portions of *ADVANCE*

These two contractual issues, both with the universities and with Motorola reflect the non-technical difficulties of a public-private partnership. The method of contracting used in ADVANCE for distributing funds between public and private organizations was one approach. There may be others including outright grants, which is an extreme solution in terms of relinquishing control. As with any administrative process, excellent communication and explicit, even-handed application of procedures can help to facilitate the difficulties of this unusual institutional format. The ultimate lesson in these areas was that commitment to an end goal allowed procedures to be developed which enabled the project to proceed.

3.3 Project Management Methods

Over its five year duration, the managers of the *ADVANCE* Project have used various project management methods, Essentially, these methods are drawn from:

1. construction contract management; and

2. the computer science subfield of software development using the military requirements specifications approach.

Construction management methods ranged from highly detailed critical path analysis methods to more generalized procedures involving milestones. Typically, several hundred specific tasks were defined, related and monitored through monthly progress reports. Motorola and IUTRC, as well as DeLeuw, Cather & Company and the project office, each devoted significant manpower to these tasks throughout the project.

The requirements specification approach to preparing a detailed system design has developed out of military software procurement processes. The approach may be briefly described as one of first describing the functional requirements for the desired system, and then making a detailed specification of the system requirements, This method envisages that the technology is relatively mature, and the challenge is to design a specific application. As discussed previously, these conditions were not present in the *ADVANCE* Project.

Several problems were experienced in attempting to apply the requirements specification approach. Most problems centered on having little experience with this approach. Most participants questioned whether this approach was suitable for a system that requires solving many research problems during the design process.

In a large-scale project such as ADVANCE, detailed management of personnel and budgets are clearly necessary. The time-honored method of dividing large tasks into smaller subtasks and even subtasks is clearly an appropriate management strategy. How much effort should be expended in monitoring this system is a difficult and contentious question that tends to bring managers into conflict with the designers being managed.

The general experience with ADVANCE can be summarized by stating that more aggregated techniques proved to be more acceptable to designers than more detailed techniques. Given a milestone chart that highlights interfaces between parties, a group of project leaders could better visualize their task and discuss deadlines and progress towards them in a meaningful way. Whether the more detailed description of tasks provided any useful insights or measures of progress was continuously debated.

A related question concerns budget planning, both for annual work programs and the entire project. As already noted, the budget prepared during the feasibility study was quite incomplete. An attempt was made shortly after to devise a budget for the design phase. The difficulty with these budget-malting processes was that the budget planners were always in the position of advocating the implementation of a proposal or a proposed solution to an unsolved problem. If they erred on the side of insuring the successful solution of the problem, the budget could be so large as to be rejected. On the contrary, if they kept the budget low, so as to be a more attractive case, then the project is more likely to fail. Budgeting, then, is another conflict of interest dilemma faced in such projects.

In ADVANCE, the planners often convinced themselves the design problem was substantially easier than turned out to be the case. Variations on these themes occurred each time budgets were prepared, although the budget for ADVANCE stabilized about mid point in the design phase.

A different design approach, known as ***rapid prototyping*** may have helped to avoid some of the early problems. In rapid prototyping, emphasis is placed on quickly designing and implementing prototypes of the desired system. The first prototypes are rough and simple, but they prove or disprove concepts and identify design problems. Subsequent prototypes are more detailed and sophisticated. Competing designs may also be explored in prototypes prepared in a parallel manner. This was used to a limited degree in the in-vehicle system design, but not without problems for those designers, the communication system designers, and the TIC developers.

Clearly, the *ADVANCE* Project is not the first project to face these questions. Although project management was identified early by both IDOT and Motorola as a difficult issue, the interviews with six prospective project management consultants provided no assurance that anyone knew how to manage such a project in a public-private partnership.

ADVANCE used various traditional and non-traditional project management methods. Undoubtedly, experience and a willingness to keep the whole project in focus and perspective are important ingredients of success. The use of milestones rather than detailed procedures worked reasonably well. However, one could argue that this was a result of most problems being defined and addressed by the time this technique was used.

3.4 Project Leadership

At the time this paper is being written, seven years have elapsed since the March, 1989, meeting that was the genesis of the *ADVANCE* Project. Few of the persons that attended the meeting are actively involved in the Project today. Equally important, the supervisors of many of the leaders of the project have changed in this seven year period. This project illustrates that technology development efforts require a long time to bring to fruition, and therefore, they require unusual focus and persistence to achieve positive results. Many of the leaders of this project found this length of time to be extremely long in terms of their previous professional experience.

Equally important, supervisors typically evaluate the success of projects under their purview on an annual basis, or less; likewise, their success as managers is evaluated on the same basis. A long term development effort of the nature of ADVANCE is in conflict with this time scale. One final comment on experience. Everyone involved in this project had prior experience in related efforts. However, no one had the experience in all facets of the project or large scale technology development and implementation effort involving a public-private partnerships. All of the parties to the *ADVANCE* Agreement committed significant resources to the project. All parties worked diligently in a spirit of cooperation which was evident not only in technical areas but also in the commitment of public information, audit and administrative staff who were brought into *ADVANCE* by the parties.

Much of what was accomplished was learning by doing. But the learning was a joint experience and should result in future efforts proceeding more smoothly.

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Council on Governmental Relations (1993) The Bayh-Dole Act, A Guide to the Law and Implementing Regulations, Washington, D.C.

Texas Transportation Institute (1990) *Mobility 2000 Workshop on Intelligent Vehicles and Highway Systems, Executive Summary, and Reports on the Major Aspects* of *IVHS,* Texas A&M University, College Station, Texas.

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APPENDIX B

DEVELOPMENT OF THE RF SUBSYSTEM FOR *ADVANCE*

Ray Makaras
Motorola

Herb Nitz
De Leuw, Cather & Company

DEVELOPMENT OF THE RF SUBSYSTEM FOR *ADVANCE*

EXECUTIVE SUMMARY

The development of the RF subsystem for *ADVANCE* met the challenges of matching existing communications technology with new ideas from the ITS world. This report documents the development of the RF subsystem, the alternatives and subsequent challenges encountered, and the lessons learned.

On the surface, providing two-way wireless communications between mobile users and the Traffic Information Center (TIC) meant that a variety of options could be used. The intent to focus on proven technology helped narrow down the field, however new approaches within the ITS world could not be ignored. Once the desired option was selected, the challenges lying within it presented unanticipated problems that needed reasonable solutions for all related subtasks to proceed. The many results throughout this project are expected to offer valuable insight to future developers of RF communications for ITS applications.

The RF communications system provided the capability for data transfers between the probe vehicles and the TIC. The inbound direction to the TIC consisted primarily of travel time reports. The outbound direction primarily supported TIC informational broadcasts to all probe vehicles of updated link travel times.

The initial RF communications system plan was to implement a 4800 bps over-the-air data transmission system to transport two-way data between the Traffic Information Center and 5000 vehicles. Technology limitations, lack of RF spectrum, and messaging structure, among other things, forced a redirection to consider higher speed hardware. A 19.2 kbps system, called RD-LAP, was introduced that would operate at four times the speed, be twice as efficient, and was becoming commercially available.

However, software development testing revealed that messages were being lost as the modems were unable to keep up with the processing demand. This was subsequently corrected with a software routine. Furthermore, the manufacturer experienced numerous delays in the production of the 19.2 kbps modems for *ADVANCE*.

To prevent delay to the project, alternate technologies were investigated to supplement or replace the RD-LAP system. FM subcarrier and private packet data radio were considered, however neither could handle the large communications load imposed by 2-way communications between the TIC and 3000 vehicles. The FM subcarrier system also had performance deficiencies, such as severe multi-path interference, while private packet data radio was cost prohibitive due to the tariffed nature of the system.

A new development was introduced in two-way mobile radio, called MIRS (Motorola Integrated Radio System), that could use a 64 kbps data rate in the same RF channel bandwidth being considered. The MIRS system was modified for *ADVANCE* and thoroughly tested. The MIRS system performed extremely well, delivering packet data at channel capacity rates with few errors and no overrun problems. Unfortunately, at this stage, *ADVANCE* was re-evaluated to a targeted deployment and subsequently field deployment of the MIRS system never occurred.

The project was concluded with more than 75 installed mobiles utilizing the 4800 bps system. System evaluation testing revealed some message loss and modem lockups. This was traced to the Mobile Navigation Assistant (MNA) inability to process the constant outbound data load while servicing internal navigation routines. The project testing phase was concluded by reducing the TIC message outbound rate from one message every two seconds to one message every four seconds, a rate at which the MNA could keep up.

The experiences of the RF communications system development for *ADVANCE* proved very valuable. Defining factors include the RF spectrum, available technology, messaging structure, and related hardware.

The major factor for the RF communications system was timing. "Off-the-shelf' technology had not progressed to the point where high speed heavy mobile data communications was readily available without major modifications for *ADVANCE.*

Most metropolitan areas are saturated when it comes to two-way radio bands. The available technology will determine the bandwidth needs, in addition to the particular RF frequencies. It may be necessary to support an iterative process, as happened in *ADVANCE,* where hardware and RF spectrum will continuously be re-evaluated to zero in on a suitable RF transmission product that works within an available band.

Furthermore, the desire for high speed data radio transmission cannot ignore the capability of the terminal equipment and its applications. Careful coordination is required between communications and applications to ensure the terminal equipment will accommodate a high data rate.

Finally, market potential for the technology and the product is critical to successful deployment and consumer acceptance. The partnership between public and private enterprise has to meet varying goals, profitability being the key for private enterprise. A functional, successful implementation must consider the ability of the consumer to afford this technology.

In their present states, the 19.2 kbps RD-LAP system and the 64 kbps MIRS system most likely would be successful today for a large scale deployment.

DEVELOPMENT OF THE RF SUBSYSTEM FOR ADVANCE

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1.0 INTRODUCTION

The ultimate goal of the *ADVANCE* project was to provide dynamic route guidance and navigation to motorists while using those same vehicles as data probes to accurately assess traffic congestion conditions within the test area. The development of the RF subsystem for *ADVANCE* had to meet the challenges of matching existing communications technology with new ideas from the ITS world. This report documents the development of the RF subsystem, the alternatives and subsequent challenges encountered, and the lessons learned.

1.1 Acronyms and Definitions

Acronyms and definitions are contained in the *ADVANCE* System Definition Document #8020.ADV. To aid in reading this report, several of the more common terms are defined below.

COM	RF Communications System
dB	Decibel
ITS	Intelligent Transportation System
FCC	Federal Communications Commission
FM	Frequency Modulate
FSK	Frequency Shift Key
kbps	Kilobytes Per Second
MHZ	Megahertz
MNA	Mobile Navigation Assistant
RF	Radio Frequency
TIC	Traffic Information Center

1.2 Authors

The authors of this report, involved in the development of the communications subsystem for *ADVANCE*, are as follows:-

Ray Makaras

Mr. Makaras is a senior communications engineer with Motorola and was responsible for the design of the RF communications system used in *ADVANCE.* He also was responsible for installation and maintenance of the Mobile Navigation Assistant (MNA) units in the vehicles.

Herb Nitz

Mr. Nitz is a communications engineer with De Leuw, Cather & Company. He assisted in the evaluation of communication alternatives for *ADVANCE* and with system integration and testing.

1.3 Intended Audience

The audience for this report is intended to be those that are technically interested in the communications system for *ADVANCE* and have a basic understanding of RF communications.

Researchers, designers, developers, and integrators of ITS are expected to benefit from the lessons learned from *ADVANCE*.

1.4 References

The following reports and documents would be of interest to the reader desiring further information on *ADVANCE* and its communications system:

- System Definition Document #8020.ADV.06-2.0.
- Requirements Specification Document #8 100.ADV.05-2.0
- Interface Control Specification Document #8110.ADV.05.20
- Data Communications Infrastructure for Illinois Dynamic Route Guidance Demonstration, by Ray Makaras, Motorola, Inc., December 19, 1990.
- RF Data Communications Coverage Test Report - *ADVANCE* Release 1 - 4.8 kbps MDC4800 Protocol, by Ray Makaras, Motorola, Inc., July 19, 1993.
- RF Data Communications Coverage Test Report - 64 kbps MIRS Protocol, by Ray Makaras, Motorola, Inc., May 20, 1994.

All of the above documents are available on the Internet at the following address:

- http://ais.its-program.anl.gov/

1.5 Report Organization

This report presents the introduction in Section 1; the purpose of the report in Section 2; the methodology and results of the RF communications development in Section 3; and the report summary in Section 4.

2.0 PURPOSE OF THIS REPORT

The purpose of this report is to document the development of the RF communications system for the *ADVANCE* project and provide lessons learned from the development, design, and implementation of the RF system.

It is intended that the valuable experiences of the *ADVANCE* project may be useful to those currently involved or will be involved in developing future wireless communications for Intelligent Transportation Systems.

3.0 METHODOLOGY AND FINDINGS

3.1 Background

The development of an RF communications subsystem for the *ADVANCE* project had brought with it a number of challenges. On the surface, providing two-way wireless communications between mobile users and the Traffic Information Center (TIC) meant that a variety of options could be used. The intent to focus on proven technology helped narrow down the field, however new approaches within the ITS world could not be ignored. Once the desired option was selected, the challenges lying within it presented unanticipated problems that needed reasonable solutions for all related subtasks to proceed. These challenges will be the subject of this document. The many results throughout this project are expected to offer valuable insight to future developers of RF communications for ITS applications.

3.2 Initial Plan

ADVANCE was to be the largest ITS operational test of dynamic route guidance in the world, with up to 5,000 vehicles operating over a 300 square mile area in the northwest suburbs of Chicago, Illinois. The project boundaries roughly follow Harlem Ave to the east, IL Route 59 to the west, Lake-Cook Road to the north, and US 20 to the south, and are further defined in the System Definition Document #8020.

The concept of *ADVANCE* was to use vehicles equipped with navigation equipment as roving traffic probes. As probes, the vehicles report travel times for the road links traversed within the test area. This information was automatically collected by on-board equipment and transmitted over the RF data network to the TIC. No involvement of the driver was required. This field operational test was targeted to measure road network performance, monitor vehicle locations, detect incidents, and produce driver guidance information in the context of a suburban arterial network.

The RF communications provided the capability for data transfers between the probe vehicles and the TIC. The inbound direction to the TIC consisted primarily of travel time reports. The outbound direction primarily supported TIC informational broadcasts to all probe vehicles of updated link travel times.

Design Criteria

Design criteria was established early in the project to highlight pertinent communications requirements:

- Restrict communications development to a minimum. This decision, made due to cost / risk considerations, effectively chartered the Communications System (COM) design to pursue developed RF data communications technologies and available equipment from manufacturers. It also restricted the frequency search efforts to portions of the spectrum where equipment was available for use.

- Cover the defined test area. An initial test area, encompassing approximately 300 square miles of the Chicago northwest suburbs had been defined.

- Provide for communications for a fleet of 5000 vehicles. This fleet was reduced later to 3000 vehicles due to funding considerations.

- Provide for two-way communications. Communications was required for inbound probe reports and other messaging; and outbound traffic updates and other messaging to all vehicles; as well as directed messaging to individual vehicles.

- Provide for a staged growth. The Project evolved in several phases, with an initial Test phase before large scale roll out commenced. Communications was necessary early in both phases, with equipment to match the increasing vehicle fleets. Communications was required seamlessly throughout, without interruption to vehicles already in service, as the fleets grew.

- Messaging was not Public Safety critical. While a high degree of messaging reliability was sought, it was determined that an occasional message lost was not detrimental to the performance of an individual unit, nor the overall system. No elaborate "guaranteed message delivery" safeguards were required, and it was not required for the TIC nor the vehicle Mobile Navigation Assistant (MNA) to be aware that a message had failed in delivery.

- Provide communications without delay. The "real-time" nature of dynamic data and an ever changing street traffic condition situation, required that there be minimal delay in obtaining traffic information from the TIC, or reporting the traffic conditions that the probe vehicles encountered. While internal delays in the ITS system could be controlled and minimized; it was unacceptable to wait long periods to transfer time critical data over the RF link. This requirement effectively dictated a dedicated communications system exclusively for ITS - sharing communications resources with other users that could introduce their "peak" loads and cause ITS communications to wait was unacceptable, especially since other mobile users tended to "peak" their usage at the times of greatest traffic congestion.

Coverage

Existing two-way radio technology was considered for the *ADVANCE* communications subsystem. The intent was to utilize proven RF high speed data communications in one of the following frequency ranges:

- 450-494 MHZ
- 806-821 MHz
- 821-824 MHz
- 896-902 MHz

Other frequency ranges were not considered due to the effects of interference potentials, poorer physical characteristics, and other regulatory restrictions.

Large metropolitan areas, like Chicago, generally experience heavy RF spectrum utilization. This was confirmed after a number of RF frequency spectrum searches in the Chicago area found no unutilized frequencies in the entire 806-825 MHz or 450-512 MHz two-way radio bands. This problem was solved by leasing the usage of a channel from a local communications service provider. Two additional channels were optioned for usage at a later date.

A propagation study over the test area was conducted to determine the RF coverage while maintaining 90% message reliability under limiting conditions. The results showed that a single radio site could cover the entire test area from a high central location. The system design utilized a 195 foot high building in the south central portion of the test area for the base station, operating at 100 watts, 853.0625 MHz into 12 dB gain for outbound messaging. (Inbound messaging transmitted at 3 watts, 806.0625 MHz into 3 dB gain.)

Further detailed coverage tests were conducted after the installation of the fixed site equipment which uncovered a manufacturer's defect in the antennas. Replacement of the antennas resulted in a greater than 99% coverage throughout the test area, defined further in the MDC4800 Coverage Test Report, dated July 19, 1993.

MNA Communications

The concept for the MNA was to be capable of autonomous operation - i.e.. that the MNA would continue to function, with reduced capability, when RF data was not available. RF infrastructure investment would be on a limited scale, confined to the *ADVANCE* test area - but the MNA's were to continue to function anywhere a road and a map database was available. The dynamic area could readily be expanded at a later time - after ***ADVANCE*** was proven to be feasible and economically viable.

The communication topology for the MNA had two options: a centralized versus a distributed system, For a centralized system, the route planning would be performed in a large central processor at the TIC and then transmitted out to the respective probe vehicle. It was determined that a centralized system could not reasonably be implemented due to the substantial communications load.

For a distributed system, the route planning needed to be incorporated into the MNA. Link data would be transmitted to the MNA, where the MNA would then process the data and select a particular route. The distributed route planning approach, when applied against the project goal of 5000 reporting vehicles in the field, led to the first initial estimations of required communications capacity. Investigations into the current state of the art for business and public safety communications, at RF data rates of 4800 bps, revealed maximum tolerable loading of 125 mobile units in use, per RF channel. Other factors, such as message size, message quantity, and allowable delays for response, would further impact the loading. Evaluation of these factors resulted in the finding that *ADVANCE* would need RF spectrum resources on a larger scale - on the order of 40 RF channels if a 4800 bps system was used. See Section 3.3 for a further discussion on channel needs versus data rates.

Message Structuring

Noting the bandwidth limitation and the significant amounts of data to be transferred between vehicles and the TIC, the initial design was evaluated with the intent of optimizing the messaging traffic that would be presented over the RF data system.

Analysis of the initial requirements and two-way RF data communications revealed that one-on-one transactional messaging was extremely inefficient when the same traffic update message had to be delivered to hundreds of vehicles. Since only the inbound probe reports were unique, it was decided to broadcast the outbound messages to all vehicles simultaneously. By broadcasting the outbound messages, the requirement. for individual addressing was removed from the communications protocol. However, the message acknowledgments had to be eliminated in the process.

A structure evolved where identical messages were broadcast on the outbound channels, and individual inbound messages were sent on the inbound channel, with mobiles separated into groups locked onto a given channel pair. It was decided not to permit mobiles to roam from one inbound channel to another due to the unpredictability of the inbound load. This locked inbound structure also simplified the evolutionary growth as additional units were added - more channels were able to be added without affecting existing users.

A decision was reached to binary encode all message data for efficiency and to minimize the inbound transmission times. The Interface Control Specification, Document #8110, was prepared, defining exact messaging format and bit definition. Under this format, it was possible to generate an inbound probe report in under 50 bits. Outbound messages, however, were compacted and then appended together into messages of 240 bytes (maximum under the protocol) in order to minimize wasteful protocol overhead.

In order to control potentially runaway inbound message traffic under extreme conditions, two concepts were defined in the messaging structure: threshold limits and stochastic throttling, the latter never being implemented. Threshold limits were designed to limit the inbound data on a global basis. Probe reports are generated measuring the time consumed in traveling a predetermined link, and then compared against a preprogrammed expected travel time. Provision was made to be able to adjust the deviation (threshold) before a mobile generated a transmission, screening out minor deviations, and allowing for major deviations to be set on a global basis (weather, snow). In case of non-global conditions, mobile transmissions could also be limited stochastically (random members would be inhibited from transmitting). Both these concepts provided assurance that communications could be maintained under severe overload.

Mobile Hardware

Cost considerations were a major factor in *ADVANCE*, primarily in the mobile unit. Consequently, selection of the lowest cost mobile radio was a key factor.

Conventional high power two-way radios, coupled with an external data modem resulted in a cost prohibitive package. Over a third of the cost of the mobile communications unit was concentrated in the mobile power amplifier, and another equal third in the external modem.

Wireless portable computing was in the initial stages, and a major manufacturer had developed an integrated two-way data radio and modem on a single circuit card. This product, with its low power (3 watt) transmitter, was “off-the-shelf”, thus it was selected and incorporated into the system design. The limitations of this approach were limited environmental performance, operation at 7.2 volts DC (intended to be operated from battery); and lack of external packaging.

Since the initial plans for the MNA included voice recognition capability as an option, an external “option box” containing both voice recognition, RF data radio, and the shared power supply and interface circuitry were assembled. This configuration was nearing Field Trial completion when the voice recognition option was eliminated, leaving the option box strictly for the two-way data radio, eliminating some cost savings from sharing resources with the voice recognition. These costs now totaled more than a commercially available vehicular radio modem, the MRM420. The

MRM420 offered a complete, proven package, with data rates at 4800 bps and environmental specifications rated for vehicle trunk applications - and expansion to higher speed 19.2 kbps under development. MDC4800 was the data protocol utilized for 4800 bps transmission. Consequently, the “option box” approach with the integrated two-way radio/modem was replaced with the MRM420 vehicular radio modem.

3.3 Setbacks and Redirections

Once the initial concept had reached the development stage, various problems arose that forced the investigation of alternate communications techniques for use in *ADVANCE*.

The 4800 bps over-the-air data rate selected for the first phase of the *ADVANCE* RF Data Communications system was the industry / technology limit at the time. However, even with the defined broadcast architecture, binary message encoding, throttling, and the decision not to send residential street information over-the-air; the median RF message loading projections showed that 20 RF channels would be needed to transfer the data for a fleet of 5000 vehicles, reduced from the projected 40 RF channels described in the initial plan. Nonetheless, RF resources of this magnitude were not attainable, thus higher speed data rates were necessary.

The ITS program, however, was not unique in the requirement for higher speed. RF communications equipment manufacturers, in response to other needs, were pursuing development of higher speed protocols, and that development had reached initial equipment field deployment. The most promising, a 19.2 kbps protocol - RD-LAP, was planned to be retrofittable into the MDC4800 equipment infrastructure.

The 19.2 kbps RD-LAP protocol offered several advantages. It was four times faster than the MDC4800 protocol over the air, more efficient in the encoding / decoding schemes that are necessary for RF Data transmissions (nearly twice as efficient), and is transparent to end user applications. Conversion would only affect the RF COM portion of the project, and require essentially no change to the TIC or the MNA. By utilizing RD-LAP, the full deployment RF channel requirements were reduced from 20 channels to 3 channels, now an attainable quantity, for the original deployment of 5000 vehicles. The infrastructure equipment was already available - and the RF modem (MRM420) with RD-LAP was planned to be available within 6 months, and retrofittable.

The design was changed to accommodate the new protocol. One MDC4800 RF channel would be used for the initial first phase development of approximately 100 units. In the second stage, one 19.2 kbps channel would be added and the MDC4800 channel converted, and finally a third channel would be added to complete the system for full deployment.

During testing of the messaging software development phase, it was observed that a significant portion of messages that were sent were “lost” with the MRM420 utilizing RD-LAP. The test was conducted in a “closed”, high signal strength environment, thus R.F propagation was ruled out as the cause. Subsequent, detailed investigation by the RF COM engineers and the manufacturer revealed that the message loss was caused by the RF modem failure to process the messages as fast as they were being sent. In effect, the RF modem could not keep up with the RF channel capacity.

The communications RF modems (MRM420) are optimized for individual transactional messaging - where a message is sent, then a wait period elapses for a response. In this case however, where messages were constantly “streamed” on outbound, with an occasional inbound transaction, the RF modem simply could not keep up with the processing demand, resulting in lost messages. This stress on the RF modem was unique to ITS communications. Most two-way systems depend on high quantities of individual transactions, while paging and other “streaming” data services are one-way, The combination of high outbound and inbound messaging placed a unique stress on the mobile device in this type of ITS architecture.

To compensate for this problem, a software routine was developed to limit the outbound message rate to one message every two seconds. (The maximum channel rate had been slightly greater than one message per second). All outbound messages originated from the TIC, thus the rate was controllable.

The small quantity at this first phase (100 units) did not justify a unique equipment redesign. The future RD-LAP modem, however, intended to accommodate this design requirement.

Unfortunately, the manufacturer experienced numerous delays in providing the RD-LAP 19.2 kbps modem. The project could not wait for this modem, accordingly, alternate techniques were investigated to supplement or replace the RD-LAP proposal. In late 1993, FM subcarrier and private packet data radio services were considered. The subcarrier technology had some inherent deficiencies, subject to severe multipath interference, atmospheric changes, and the need for considerable custom redesign. Packet data services proved to be too costly because of the tariffed nature for usage.

While still other promising technologies were emerging, such as Cellular Digital Packet Data (CDPD), they were still in development, or unsuitable due to cost, application, or major development risk.

With the continuing delay in the availability of the 19.2 kbps MRM420 impacting full scale deployment planning, and an investigation launched into possible alternate product not yielding positive results; attention was redirected on a broader scale into other alternatives.

The most promising was the new technology development that was being introduced by a leading two-way radio manufacturer in the first quarter of 1994. This technology was a radical change in the basic modulation and hardware platforms that had dominated mobile radio for the past 40 years, code named MIRS, or Motorola Integrated Radio System.

MIRS utilized 64 kbps Quadrature Amplitude Modulation (QAM) in the generation of a digital data stream that was converted to analog voice, where all prior systems utilized Frequency Shift Key (FSK) of an FM signal. To summarize the technology, the important differences to the RD-LAP option were:

- A 64 kbps data rate was possible in the same channel RF bandwidth as before.
- An entirely new hardware platform was needed - no compatibility was possible.
- The software for the system could not support packet data at the time (voice only).
- The higher data rates would result in a reduced coverage zone.
- New mobile radios would be needed as well.
- The higher data rates needed only two RF channels for the *ADVANCE* Project at 5000 vehicles, with some spare capacity.

All items, except for the software for data only transmission, were available or could be addressed immediately. In order to ensure that the required software would indeed happen, and avoid the delays that occurred with the MRM420 the software development effort was funded directly by one of the project partners. The funding provided for license to use the software for *ADVANCE* only.

The project plans were redirected to use the MDC4800 for the first test phase only, and then convert to the MIRS system for the .following phases.

The MIRS equipment was ordered and assembled in the development lab. Coverage was revisited with computer simulation, predicting reduced but sufficient coverage for the test area. Subsequently, a test transmitter was installed at the RF site, and coverage was retested at the higher data speeds. The test again verified the prediction tools, all locations within the test area experienced better than the required 90% reliability (64 kbps Coverage Test Report, dated May 20, 1994).

By the start of 1995, the 64 kbps QAM system was operational in the Lab, and extensive testing was started, using five mobile radios mounted in a fixed location.

After some minor software bugs were corrected, it was found that the system worked extremely well. The packet data was delivered at channel capacity rates with few errors and no overrun problems in the mobiles. After validation, the system was ready for movement to the RF site, and mobile installation, Unfortunately, field deployment of this system never occurred. *ADVANCE* was re-evaluated to determine the future of the deployment. It was decided that although *ADVANCE* was starting to meet expectations, there was not a path to full deployment on a commercial basis. There is little doubt, however, that it would have met requirements had it been deployed.

3.4 Final Implementation

The project was concluded with the MDC4800 system and 80 installed mobiles operating at 4800 bps. During the total system evaluation testing phase in 1995, where vehicles used the system extensively, some outbound message loss and RF modem lockups occurred.

While the initial assumptions were that the problems were due to the RF modem, subsequent analysis proved that this was not the case. Faced with the outbound data load on a constant basis, the MNA would shut off the communications port in order to service internal navigation routines. The MRM420, with nowhere to pass on the never ending stream of incoming messages, would overrun its buffer space and shutdown, losing messages in the process. The project testing phase was concluded by reducing the TIC message outbound rate to a message every four seconds, a rate at which the MNA could handle all the messages. The Targeted Deployment proceeded with only minor communication problems.

4.0 SUMMARY

The present state of RF communications is further along than it was during the development and implementation stages for *ADVANCE*. The major setback for the RF subsystem was timing. It is mutually agreed by project staff that the MRM 420 modem utilizing the RD-LAP protocol would be successful today for a large scale deployment, as would the MIRS 64 kbps QAM modem. For *ADVANCE* however, “off-the-shelf’ technology had not progressed to the point where high speed heavy data communications was readily available without major modifications.

The search for available RF spectrum can seriously impact the implementation of an ITS concept design. As stated previously, most metropolitan areas are saturated when it comes to two-way radio bands. To make matters worse, the desired commercially available radio equipment will most likely operate in those saturated bands, thus limiting your selection of candidate equipment.

Another factor to be considered for successful implementation is the messaging structure. Some candidate technologies, such as FM subcarrier and packet data radio services, were eliminated because of the large size of the messages and the rate of transmission for the messages, although cost and performance also impacted the candidate technologies. The large data load and required high speed rate of transmission of *ADVANCE* are still impediments for these technologies today, however they undoubtedly would hold promise for developing ITS technologies that match their inherent benefits.

Finally, market potential for the technology and the product is critical to successful deployment and consumer acceptance. The partnership between public and private enterprise has to meet varying goals, profitability being the key for private enterprise. A functional, successful implementation could be curtailed by the inability for the consumer to afford this technology.

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APPENDIX C

SYSTEM INTEGRATION CHALLENGES IN DEVELOPING *ADVANCE*

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SYSTEM INTEGRATION CHALLENGES IN DEVELOPING *ADVANCE*

EXECUTIVE SUMMARY

This paper focuses on the integration aspects of the *ADVANCE* system. Relevant system integration issues and challenges were captured from project meeting minutes, memos, discussions with ADVANCE personnel and author recollections. The findings have been separated into five categories: General, MNA, TIC, TRF, and COM. The majority of the findings relate to the concept of how the system integration team was able to increase communication between the system, subsystem and component designers, developers and integrators. Also, discussed is the importance of communication within each organization and the need to remain open and accessible with respect to transfers of information. The findings also show the need for thorough documentation to be developed at each stage of the project. To ease the burden on the integration process, the use of releases is a wonderful concept. In order for it to work effectively, it must remain on schedule. The findings show that there were difficulties in managing subsystems at different release levels and that there is a need for thorough testing by designers and developers prior to releasing subsystems to integrators. The system integration testing team was challenged with managing the different releases and their respective sets of requirements and capabilities.

In summary, the recommendations for future similar systems are:

- Provide a means for effective communication between designers, developers and integrators. Monitor the communication and provide means to allow for feedback.
- Require thorough documentation at all stages of the Project.
- Perform system integration testing for each release. Avoid, if possible, testing mixed releases.
- Pretesting of subsystems and components before integration testing is essential.
- Tools to aid integration testing should be designed as part of the overall system design.
- Deficiencies uncovered during testing should be tracked to ensure proper and timely resolution.

SYSTEM INTEGRATION CHALLENGES IN DEVELOPING *ADVANCE*

TABLE OF CONTENTS

1.0 INTRODUCTION

This paper will discuss the integration aspects of the *ADVANCE* system. *ADVANCE* consists of four (4) distinct subsystems: Mobile Navigation Assistant (MNA), Traffic Information Center (TIC), Traffic Related Functions (TRF), and Communications Infrastructure (COM). A substantial hurdle in this project was to develop these subsystems independently by a variety of personnel from different backgrounds operating in distinct, separated geographical sites and then integrate the subsystems into one system which would operate as designed. Discussion will revolve around the challenges undertaken and the lessons learned throughout the system integration process. It will cover the details of the predesign stage, design stage, code and test stage, and the integration stage, each of which involved the four subsystems.

1.1 Acronyms and Definitions

For a complete listing of acronyms, definitions and abbreviations refer to Appendix A of the System Definition Document #8020.ADV.06. To aid in reading this report, several of the more common terms are defined below.

COM - RF Communications subsystem of *ADVANCE*

DF - Data Fusion, a TRF algorithm on the TIC. Data Fusion acts as an intermediary between external components and other TRF components. It screens data received from detectors and probe vehicles and aggregates this with all other on-line data to estimate link travel times for the last five (5) minute interval.

FHWA - Federal Highway Administration. One of the founding Parties. FHWA is responsible for the overall evaluation of the *ADVANCE* Project.

ID - Incident Detection, a TRF algorithm on the TIC. The detection at the TIC of activities on the roadway that significantly reduce capacity of the roadway from the expected capacity at a particular time. The detection may be based on input from probes, fixed detectors, anecdotal sources and such other data as may be available.

IDOT is responsibleIDOT - Illinois Department of Transportation. One of the founding Parties.
for providing project management for ***ADVANCE*** and for operating the TIC.

IUTRC - Illinois Universities Transportation Research Consortium. One of the founding Parties. IUTRC is a non-profit corporation owned by Northwestern University, the University of Illinois at Chicago, the University of Illinois at Urbana-Champaign, and the Illinois Institute of Technology.

Link - A pair of adjacent segments and its associated data within a given network layer. A link consists of the portion of road from the detected beginning of a segment to the detected beginning of one of its successor segments.

MNA - Mobile Navigation Assistant. An in-vehicle navigation system designed and built by Motorola that determines vehicle position, performs route planning based on current traffic information, and provides dynamic route guidance information to the driver.

Motorola - One of the founding Parties. Motorola is providing the in-vehicle system as well as the RF communications systems.

Segment ID - A unique ID that identifies each roadway segment. The ID consists of twenty-three (23) bits as assigned by Navigation Technologies, the map database provider.

Short Link - A link which has an approximate travel time of less than two (2) seconds. These short links are often turn bays or roadways connecting one-way streets separated by a grass median.

Static Profile - Static information of the roadway link including day type, link ID and average travel times for a specific time period.

SPU - Static Profile Update, a TRF algorithm on the TIC. SPU uses the historical static profile along with current travel time information to create an updated historical static profile.

TIC - Traffic Information Center. The TIC consists of the hardware, software, and operations personnel in a centralized facility. It communicates to and receives information from probes and external systems.

TRF - Traffic Related Functions. TRF is a subsystem consisting of data fusion, incident detection, travel time prediction and static profile update algorithms.

TSC - Traffic Systems Center. Operated by IDOT to monitor and control the flow of traffic on expressways within the Chicago area.

TTP - Travel Time Prediction, a TRF algorithm on the TIC. It is used in the prediction of future short term travel times on links to be broadcast to the probe vehicles for their use in route planning.

UIC-EECS - University of Illinois at Chicago, Department of Electrical Engineering and Computer Science. Responsible for the development of the TIC and coding of the TRF algorithms.

1.2 Authors

The authors of this report were both intimately involved in the development of *ADVANCE*

David Weiss

Mr. Weiss is a Systems Engineer for De Leuw, Cather & Company. His responsibilities have included system documentation, design, and integration testing.

Syd Bowcott

Mr. Bowcott is the Chief Engineer for ITS Programs for De Leuw, Cather & Company. He has led the De Leuw, Cather & Company team which functioned as the lead systems engineer and had overall responsibility for system integration.

1.3 Intended Audience

This paper is intended to provide useful information to project managers, system developers, and system integrators to aid in future similar ITS implementations. It is intended for those that are technically interested in the *ADVANCE* Project and have a basic understanding of the project.

1.4 References

There are several relevant ADVANCE documents which provide additional information on system integration and testing. These documents are:

- Integration Program Plan (#8320.ADV.04)
- Subsystem Integration Test Plan (#8330.ADV.03)
- System Integration Test Plan (#8340.ADV.03)

1.5 Report Organization

An introduction is provided in Section 1. Section 2 discusses the purpose of the paper and Section 3 presents the findings which includes subsections on the predesign, design, code and test, and integration stages of the four subsystems. Section 4 provides the report summary. The appendix contains unresolved comments from reviewers of the report.

2.0 PURPOSE

This report is intended to provide an historical record of lessons learned from the systems integration effort in developing and implementing ***ADVANCE*** and its subsystems. While another report will deal with the technical challenges encountered in the design and operation of ***ADVANCE*** this report will concentrate on the system integration and testing challenges encountered, what impact they had and how they were met. Note that system integration involves not just making a final, working product, but integrating the designs of components and subsystems long before anything is physically built.

It is intended that this report will be useful to others that are currently involved in or will be involved in developing sophisticated Intelligent Transportation Systems, particularly those dealing with Advanced Traveler Information Systems.

3.0 METHODOLOGY AND FINDINGS

3.1 Background

System integration of ***ADVANCE*** encompasses the entire project duration. From the predesign stages to the final system implementation, system integration was a necessary part of the project. The design of each subsystem had to take into account how it would interact with the other subsystems and the overall system. It was the role of the system integration team to assure that these interactions be performed seamlessly. Throughout the system integration process numerous challenges were encountered. Each of these challenges presented a unique trial which had to be met and overcome before the project could proceed. These system integration challenges and how they were overcome is the subject of this report.

3.2 Methodology

In approaching the development of this report, it was felt necessary to include the key members of the system integration team. De Leuw, Cather & Company was responsible for the system integration and testing of ADVANCE which led to their authoring of this report.

Upon being selected, the authors took the responsibility for outlining the report and documenting what were considered the key system integration challenges in ***ADVANCE***. These challenges were based on recollections, memos, minutes of meetings and discussions with staff who were not coauthors.

3.3 Key Assumptions and Constraints

The key assumptions and constraints in developing this report are as follows:

- any biases of the coauthors would not affect the final report
- the coauthors had sufficient experience with ***ADVANCE*** to be able to document the system integration process

3.4 Findings

The system integration challenges that were encountered and how they were overcome are documented in the following sections. The challenges which are characteristic to the system integration process in general are grouped together followed by sections pertaining to subsystem specific challenges.

3.4.1 General

- The original subsystem designs were based on a set of firm requirements. Over time these requirements were modified and changed to reflect the updated direction of the project. The requirements documentation was reviewed by each subsystem developer and changes were made as necessary. This practice presented several challenges for overall system design and integration. First, the overall system capabilities were often reduced due to developers modifying the requirements for a variety of reasons (the existing system would not support them, incompatibilities in hardware/software, development time frame too great for project schedule, etc.) Second, where one subsystem reduced requirements and another did not, there were problems where functions were expecting data but it was not provided due to changes in the requirements. To overcome these challenges, data flows were checked thoroughly before final design and integration. In order for the designers and developers to improve on their communication with each other and to discuss technical difficulties in incorporating facets of the project into their subsystems, weekly status meetings were held to facilitate discussions of relevant issues and concerns.

- Subsystems were at different stages of development while integration was being performed. This presented a challenge to the test team because the test plans were developed to reflect each release. With subsystems at different releases, coordinated efforts were necessary to assure that requirements were being met for the proper release. Other challenges were in testing a subsystem which had additional capabilities which could not be supported by the other subsystems (it required inputs which were not available due to other subsystems being at earlier releases.) Although this presented difficulties, they were not insurmountable and in these instances, simulated inputs were used for testing which proved to be an invaluable solution.

- The code and test stage of the development involved coding of the algorithms which comprised each of the subsystems and then testing each subsystem. The coding and testing was performed by the developers prior to being released to the integration test team. It was generally found that additional testing was necessary prior to integrating with other subsystems. The level of pretesting by developers was below the expectations of the integration team, but the additional testing allowed the test team to attain a greater understanding of the subsystems and the complexity of their implementation.

- System integration testing involved numerous inputs being entered into the system by the test team. Due to the five (5) minute cycle of the TIC and TRF algorithms along with the twenty (20) minute prediction messages developed within TTP, there were times in the testing process where it would have been helpful if a series of links where tests were performed could be reset to a state where no link update messages were being transmitted. This would have enabled tests to be repeated for reliability, reduced testing time, and enabled testers to create a baseline travel time road network at any time. The test team was challenged to use this time effectively. To this end, additional integration tests were performed as testers waited for the travel time impacts to expire.

- In developing the System Integration Test Plan document, it was important to have routes developed for performing the tests, especially for dynamic route guidance re-route testing. It was built into the design of the MNA that it would choose a "good" route but not necessarily the "best" route. This created the need to postpone the writing of many of the specific details of test plans involving predetermined routes. One other factor affecting the writing of some test plans was the introduction of updated static profiles into the vehicles. Updated static profiles were usually associated with a new Release, but the data was not available to preview the potential test routes. The integration test team overcame these obstacles by performing quick turn-around on test plans once new Releases were available.

- Testing dynamic replanning posed challenges to the test team. The exact criteria for determining when a reroute was to be presented to the drivers was not fully documented due to its proprietary nature. Additionally, it was difficult to time the input of the MNA report used to create an abnormal travel time on a link which would then be avoided with the vehicles driving in route guidance. The time frame for when the link update message would be sent varied with the link's place on the queue in the message scheduler awaiting transmission to the probe vehicles. Nevertheless, integration testing was performed successfully through involving the designers in the testing and using multiple vehicles simultaneously.

- The integration team also recorded and tracked any problems encountered during testing. When a requirement was not met during testing, a deficiency report was created. This report contained the requirement being tested and a description of the exact problem encountered. These reports proved invaluable for relaying deficiency information to the system designers and developers. They also provided a means for tracking and recording problem areas and their progress towards resolution.

3.4.2 MNA

- MNA Design/Development

-The MNA was being developed by Motorola as a proprietary undertaking. In the predesign stage of the ***ADVANCE*** Project, Motorola already had an in-vehicle navigation unit in development and used this design as a building block for the MNA. Each of the parties wanted the MNA to perform certain functions to help the project reach its overall objectives. Some of these functions were to store route information, travel time information, display route map, display next maneuver, transmit a distress message, etc. It was a difficult task to incorporate all of the desired features into this preexisting system. Changes were necessary to accommodate as many features as possible. This set of desired features continued to be updated as the project proceeded. Tradeoffs were then required due to product limitations and scheduling. It should be noted that any attempt to reuse an existing product requires extensive testing by developers prior to integration testing. The main challenge was to integrate this subsystem with the other subsystems. This challenge was met and the integration team successfully integrated the subsystems which allowed the ***ADVANCE*** Project to meet its objectives and prove the probe concept.

. The MNA development team involved a large number of designers. Not all members of the MNA software development team were present at all the design meetings. It would have been beneficial to include more members of the team at all high level design meetings to address the technically challenging areas that stretched the capability of the MNA. This would have given all ***ADVANCE*** partners a better idea of the effort required and tradeoffs involved in achieving the desired functionality. The integration team overcame this weakness using off-line communication with the developers by phone conversations, written correspondence and e-mail.

- The original design offered performance and features that, in retrospect, were beyond the physical capabilities of the MNA. This was not known as the original concept began to take shape. It would have been beneficial to the designers and system integrators if significant knowledge of the MNA was known during the early stages of the project. This would have allowed the system integration team and designers to better reassess the capabilities of subsystems at each decision point in the development process as a means to guide continued development.

- MNA Testing

- The development of the MNA was performed solely by Motorola. Although Motorola was a party to the project, their software was of a proprietary nature. The integration team was not able to examine the code or algorithms related to the functions of the MNA. This was especially difficult when route guidance issues arose. The only information available was through technical discussions with the software developers. Laboratory and limited field testing of the system was performed by Motorola prior to delivery to the Project Office. Retesting was then performed by the integration test team. There were occasionally problems which were not discovered during testing at Motorola. Some of the problems encountered during testing were not discovered at Motorola due to the different testing conditions. Motorola performed their testing in the lab whereas integration team testing was performed in the field vehicles. Recreating the problem in the lab was difficult at times. By testing under a variety of conditions, the integration team and Motorola were able to identify a wide range of problems. All of these problems were then revisited by developers and then retested to the satisfaction of the integration test team.

· The system integration testing required the tester to have the ability to understand the data flow within the MNA. What seemed to be a major challenge was easily overcome because the MNA had the capability, through a special port, to interface a laptop computer that could capture incoming and outgoing RF data streams. While this tool was solely intended for use by the system developers, it was also used by the system integrators. This significantly improved the ability to perform system integration testing and trouble shooting through this capability to follow incoming and outgoing messages.

3.4.3 TIC

- Design

- Due to a tight schedule, the initial TIC interface was developed and installed with little input from the operations personnel who would eventually operate the system. This lack of feedback early in the design process caused entire development efforts to be modified in order to be useful to the system operators. As the design process continued an Operations Subcommittee provided useful feedback information to the system developers who then addressed the design issues at future Operations Subcommittee meetings. The overall system design benefitted from the increase in timely feedback into the design process.

- The TIC design used a defined navigable database which was also to be used in the vehicles. During the design process, the road segment identification parameters changed when an updated version of the database was loaded onto the system. This caused difficulty in verifying that the road network was being properly handled within the TIC. The short link resolver which had stored commonly skipped short links had to "relearn" the common short links in the system. There were also links which had not previously existed and needed to be added to the database. The entire process of updating the database became significantly more difficult than expected due to modification to ***ADVANCE'***s reference identification field (segment IDS.) This is not an uncommon problem with a road network database that needs to be updated to account for changes in geometry and additions/deletions from the road network. For ***ADVANCE,*** this problem was overcome by "freezing" the database. Future, long-term systems using similar databases will need to maintain link IDs across updates or, as a minimum, completely document all changes.

- Pretesting

  - In the early Releases, due to time constraints, parts of the TIC code were not tested thoroughly by the developers before being released to the integration team. There were times when new software was installed on the TIC but the processes using this new code were still referencing an older version of the executable file. By Release 1.5, the TIC developers and integrators had a better defined relationship and the developers were able to preload their applications for pretesting and debugging with the aid of operators and integrators.

- System Monitoring - It was critical that the system integration team have access to data streams within the TIC and to be able to monitor system information.

  - Integration testing required information on internal TIC processing to be stored and easily retrieved. Upon completion of the test, the data would be examined. There had been no provision to build this capability into the system. Log files which were originally used for system debugging had been modified to accommodate an easily understood format for the integration test team. Although a bit clumsy at times, the modified log files effectively provided the required information to the integration test team throughout the test period.

  - To enable the operator to monitor the system, it was necessary to add a window display showing the status of the various processes. When this was initially implemented, the process status display showed only the status of the process, not if data was being received and processed. The final implementation included an additional means for the operator to monitor the system. This involved displaying the last message received/sent for several major TIC processes. This was critical for the system integration testing in that it provided information on the TRF cycle, the TSC and incoming MNA reports. Additionally, this was important for system integration testing so that it could be readily known to the test team if there were any problems with the system prior to performing system tests.

  - Through verification processes of probe vehicle actual routes and the links involved with MNA reports received at the TIC it was determined that the MNA often would not transmit a probe report for a short link (e.g., a turn bay.) This prompted the need for a short link resolver due to the MNA updating position every two seconds which was sometimes longer than the time it took to traverse a short link. This resolver function greatly enhanced the accuracy of probe vehicle reporting to the TIC and thus increased the effectiveness of integration testing efforts for verifying the proper operation of the MNA and the static profile update process.

- Documentation

  - A lack of formal documentation on the TIC user interface, TIC software organization and code slowed the testing process. This meant that the test team had to work very closely with TIC developers to learn more about how to interpret the results of the integration tests. It also took time away from the TIC developers and their work towards the next releases. Even with these challenges, all testing was performed successfully and within the test period because of the cooperation of all parties.

3.4.4 TRF

- Communication amongst the TRF designers, developers, and integrators

  -The TRF algorithm designs were performed by IUTRC personnel and the software code was developed by UIC-EECS personnel. The different components of TRF (DF, ID, SPU, and TTP) were for the most part developed by different individuals, geographically separated and often at different Universities. If one designer changed the method by which they calculated a variable, another designer's equation could become impacted. It was also important that everyone knew what units the variables were in (e.g., feet, miles, meters, etc.) Lastly, if one designer stopped using a variable, the designer who calculated that variable would have to be notified so that they could stop calculating it and thereby reduce the computing load. It was found that communication between developers was critical to insure compatibility and maintain data integrity. During the intense stages of Releases 1.5 and 2.0, TRF technical meetings were held monthly. These meetings were attended by all of the designers, developers, as well as system integrators and significant problems were resolved.

- TRF Design .

  -The TRF comprised many different concepts each of which were independently designed. This led to some inconsistency in the level of documentation and the depth of the error checking involved in the algorithms. It would have been useful to the designers, code developers, and integrators if standards were used for algorithm development, documentation and procedures for following development through implementation. Even with this lack of documentation consistency, the system integrators, working closely with the developers, were able to understand the designs and provide for thorough testing.

- One difficulty of the TRF design was the gap between the designers of the algorithms and the software coders that implemented the design into executable code. In many instances, the only information available to the code developer was a design document which was written at a high level of abstraction and was not written in a flow chart format or using a structured design methodology. As mentioned earlier, for Releases 1.5 and 2.0 extensive use of meetings was the medium for exchanging information and posing questions to involved parties. Through these meetings, any gaps in documentation were closed and misunderstandings minimized.

- There was difficulty in verifying that the code that had been written was reflecting what had been designed. It was found that requiring the TRF designers to come into the TIC and physically check actual data output in order to verify proper coding of their algorithms was necessary. It was also important to have both designers and coders in the TIC at the same time. When a problem was suspected, it could be identified and resolved in a timely manner. This process lessened the time required to find coding errors, previously left to the system integrators to find. For the later releases, code walkthroughs were implemented where the code developer would explain the code to the system integrators and designers. Any uncertainties in the developer's code or discrepancies could be immediately addressed prior to bringing the algorithms on-line in the TIC.

- There was also a lack of documentation from which to understand the details of the timing within the TRF functions and how they interacted with the TIC clock cycles. Timing of tests involving the cycle of the TIC presented problems with testing of dynamic route guidance. These complications were alleviated through coordinating testing with the developers who worked to resolve any timing misunderstandings.

- Integration testing attempted to cover the realm of all possible input streams. Some of the conditions for which tests were performed were not readily handled within the TRF algorithms because they were special cases which had not been accounted for in the algorithms. One example of this is that road closures, lane closures, and incidents do not have their effects decay at the same time after the event is over. This created some confusion within TTP when dealing with unique cases such as a lane closure with an incident. Through integration testing many unique cases arose and were quickly incorporated into the TRF logic. Ultimately, all special cases were implemented in the TRF algorithms and were successfully integrated.

- As the scope of the Project changed, it was necessary to modify portions of the algorithms. Major modifications were made to the broadcast prioritization component of TTP as well as turning predictions from through maneuvers, etc. Modifications were also made to DF and

ID. It was important that designers and code developers were up-to-date with the direction of the Project and cooperated in making changes to the algorithms. When a component of an algorithm was deleted, it was decided that it should still appear in the documentation to further the state-of-the-art with a note specifying that it was not being used.

- As part of the integration testing effort, it was necessary to have the capability to modify parameters relating to the TRF algorithms. It was necessary to require designers to specify parameters that should be changeable and not hard-coded. It was also important to require designers and system integrators to work with the coders to develop the format of the data output log files. This made it easier to validate code and monitor the algorithms.

3.4.5 COM

- The challenge with the COM was that the systems integration team did not have full access to technical information regarding the design and coding of the communications system and thus only inputs/outputs could be monitored. The Project's desire to use a proven communication system technology, rather than developing one specifically for ***ADVANCE,*** was partially to blame for the problem. Full access to design information and coding is not easily obtained from companies whose products were considered. This added difficulty in generating test plans and understanding the details of this subsystem and how it interacted with the other subsystems. When questions arose, it became necessary to stop integration testing, determine the answer from other sources, and then continue with testing. While this process did cause some delays, all questions were satisfactorily answered.

4.0 SUMMARY

System integration posed many challenges to the ***ADVANCE*** Project. All the challenges were successfully met due to the cooperation and commitment of all parties involved. The major lessons learned in this area are listed below.

1. Communication between the designers, developers and integrators is essential.

2. Standard guidelines for documentation should be developed and followed throughout any such project of this size and complexity.

3. System integrators should have access to information related to all subsystems which comprise a project of this size, even if some subsystems contain proprietary information.

4. To ease the complexity of the integration testing effort, it is advised that the releases for each subsystem remain at the same level (i.e., perform all of Release 1 testing for all subsystems then proceed to Release 2. Try to avoid testing TRF Release 2 with MNA Release 1.5).

5. It is important that the designers and developers thoroughly test all subsystems before they are submitted to integration testing.

6. It is important to design into the development process a channel to provide feedback from operations personnel so that designs do not proceed in an inappropriate direction.

7. It is critical that integrators have the tools available to examine internal data flows and data values during testing.

8. It is important that during testing, the problems and requirements that are not met are recorded and tracked through resolution.

APPENDIX D

FIELD DATA COLLECTION ACTIVITIES AND EXPERIENCES IN SUPPORT OF THE FORMAL EVALUATION OF THE *ADVANCE* TARGETED DEPLOYMENT

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FIELD DATA COLLECTION ACTIVITIES AND EXPERIENCES IN SUPPORT OF THE FORMAL EVALUATION OF THE *ADVANCE* TARGETED DEPLOYMENT

EXECUTIVE SUMMARY

This paper documents how the evaluators and other parties integrally involved with the ***ADVANCE*** targeted deployment--The Illinois Department of Transportation ***ADVANCE*** Project Office; Motorola, which produced the in-vehicle navigation and real-time traffic information unit used in the tests; the Department of Electrical Engineering and Computer Sciences of the University of Illinois-Chicago, which developed the Traffic Information Center (TIC) operating system; De Leuw, Cather and Company, the ***ADVANCE*** systems integrator; and Argonne National Laboratory, the ***ADVANCE*** Evaluation Manager--implemented and maintained an evaluation data collection effort consistent with plan specifications, despite encountering numerous obstacles during the testing period. The report should be of interest to individuals or organizations charged with developing a data base for any Intelligent Transportation System field operational test. Because of the extremely tight time frame in which the various ***ADVANCE*** tests could be conducted, it was imperative that the means and procedures established for data collection be as free from delay and deviation as humanly possible. The report describes these means and procedures, both those adopted from the beginning and those for which necessity arose as tests progressed. It highlights methods which worked especially well and those which were found to be in need of adjustment; it also discusses the workability of those adjustments, The report is intended as an informal guide for ***tactical*** planners of future ITS deployments.

Operational challenges were encountered (and overcome) in attempting to meet critical test requirements, including:

*Availability and deployment of paid drivers
*Availability of project vehicles
*Route and staging area specifications
*Real-time data retrieval tracking
*Provision for unusual occurrences
*Data capture and archiving
• Survey sampling adequacy

Key findings in meeting these challenges were

1) Hiring of paid drivers for specific tests should be done based on conduct of an interview no

later than a few weeks before the start of the test. Other means of recruitment evaluation are likely to prove less satisfactory.

2) The pre-test agreement signed by “volunteer” drivers should provide for an explicit reward for timely completion of or penalty for non-response to survey instruments; otherwise, it is almost certain that the post-test survey response rate will fall short of 100 percent of target.

3) Insurance coverage should be given the highest priority for resolution before field testing protocols and schedules are finalized. In particular, persons hired for temporary driving jobs need to be provided with specific insurance coverage to limit their risks.

4) If vehicle staging areas in residential areas are used, it is not likely that all potential objections from neighboring residents can be anticipated and allayed in advance. Nevertheless, prior clearance with local law enforcement and directly-affected institutions (school, shopping areas) is essential for both logistical and diplomatic purposes.

5) Written logs should be maintained to document unusual events during tests: paper trails are vital to attempting after-the-fact diagnoses of operational problems that resulted in lost or corrupted data. Where electronic data collection is used, a backup automatic data retrieval system should be in place for all critical field testing.

FIELD DATA COLLECTION ACTIVITIES AND EXPERIENCES IN SUPPORT OF THE FORMAL EVALUATION OF THE *ADVANCE* TARGETED DEPLOYMENT

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1.0 INTRODUCTION

Integral to the targeted deployment concept for the ***ADVANCE*** field operational test was the need to collect and process field data from highly-focused tests designed by project evaluators to gauge the effectiveness and success, relative to design goals, of key system features. The intensity of focus of the test designs was dictated by the limited number of vehicles that were equipped with the ***ADVANCE*** in-vehicle navigation system and also capable of serving as mobile traffic probes. The intensity of the test protocols was dictated by the inflexible time frame in which ***ADVANCE*** equipment would be available for evaluating the various system features. This white paper documents how the evaluators and other parties integrally involved with the ***ADVANCE*** targeted deployment--The Illinois Department of Transportation ***ADVANCE*** Project Office; Motorola, which produced the in-vehicle navigation and real-time traffic information unit used in the tests; the Department of Electrical Engineering and Computer Sciences of the University of Illinois-Chicago, which developed the Traffic Information Center (TIC) operating system; DeLeuw, Cather and Co., the ***ADVANCE*** systems integrator; and Argonne National Laboratory, the ***ADVANCE*** Evaluation Manager--implemented and maintained the data collection effort consistent with plan specifications, despite encountering numerous obstacles during the testing period. The paper is not designed as an exercise in self-congratulation, but as an informal guide to the successful conduct of similar activities in other field operational tests, a guide that emphasizes teamwork, diligent effort, vigilance, and attention to detail by all key parties.

1.1 Acronyms and Definitions

All terms and acronyms used in this document that are specific to the ***ADVANCE*** project and therefore potentially unfamiliar to the reader are defined in the System Definition Document #8020.ADV, available for examination and downloading on the Internet at the following URL:

http://ais.its-program.anl.gov/

Other acronyms are spelled.out in the report on first use.

1.2 Authors

Contributing authors to this document are

(1) Christopher L. Saricks, ***ADVANCE*** Evaluation Manager, Center for Transportation Research, Argonne National Laboratory (ANL). ANL was contracted to manage the evaluation of the ADVANCE targeted deployment in April, 1995, with Mr. Saricks designated chief project liaison and ANL site manager. Mr. Saricks has been with ANL since 1979, and has over 20

years' experience and more than 50 publications in urban transportation analysis, forecasting and planning for Federal and State Governments and in private consulting. His graduate degree is from the London School of Economics and Political Science.

(2) Siim Soot, Associate Professor of Geography and Acting Associate Director, Urban Transportation Center, University of Illinois-Chicago (UIC-UTC). UIC-UTC has been actively involved in the ***ADVANCE*** project since its inception, and was responsible for the conduct of all field evaluation tests relating to the travel time prediction algorithms of the traffic-related functions (TRF) subsystem of ***ADVANCE.*** Dr. Soot directed these tests. A member of the UIC faculty since 1970, he has worked on numerous research projects funded by federal, state and local agencies, most dealing with the relationship between land use and transportation systems and how travel behavior is affected by these systems. Extensive data collection activities, including the distribution of one million survey instruments to Chicago transit users and the survey of several thousand Chicago downtown travelers, have been integral to these projects. He has published several dozen articles in academic journals.

(3) Joseph L. Schofer, Professor of Civil Engineering and Transportation, McCormick School of Engineering, Northwestern University. Dr. Schofer has been affiliated with the Northwestern University Transportation Center (NUTC) for over 25 years and has published nearly 100 papers and journal articles in the field of transportation. NUTC was a partner in the development of the original ***ADVANCE*** deployment concept, as a member of the Illinois Universities Transportation Research Consortium, and was responsible for conducting the evaluations of the dynamic route guidance and incident detection capabilities of the targeted deployment, as well as the analysis of the response of familiar drivers (residents of the test area) to the ***ADVANCE*** navigation and real-time route guidance features.

(4) Regina G. Webster is the principal of Regina Webster and Associates, a civil and transportation engineering firm located in Skokie, IL. Ms. Webster was the test manager for the evaluation tests using paid drivers that were conducted by NUTC. A registered Professional Engineer in Illinois, Ms. Webster has over 15 years experience as a traffic engineering consultant in northeastern Illinois.

1.3 Intended Audience

This report should be of interest to any individuals or organizations charged with developing a data base for any Intelligent Transportation System field operational test. It is not intended to be a catalog of "do's" and "dont's," but a chronicle and interpretation, from the perspective of hindsight, of some of the more instructive experiences in the daily process of amassing ***ADVANCE*** evaluation data, with a view toward identifying the ***a priori*** arrangements and back-up techniques that the

ADVANCE evaluation team found to be essential.

1.4 References

Readers are advised to consult each of the ten ***ADVANCE*** field evaluation test plans to obtain the appropriate background for understanding how and why each of the tests were conducted. These plans may be found on the Internet page cited above, and have the following document control numbers:

8460-l .ADV.0l	Base Data and Static Profile Evaluation Test Plan (revised)
8460-2.ADV.01	Data Screening Evaluation Test Plan (revised)
8460- 3 .ADV.01	Quality of Probe Reports Evaluation Test Plan (revised)
8460-4.ADV.01	Travel Time Procedures and Performance of Probe and Detector Data Evaluation Test Plan (revised)
8460-5.ADV.01	Detector Travel Time Conversion and Fusion of Probe and Detector Data Evaluation Test Plan (revised)
8460-6.ADV.01	Frequency of Probe Reports Evaluation Test Plan (revised)
8460-7.ADV.01	Relationships among Travel Times Evaluation Test Plan (revised)
8461.ADV.01	Incident Detection Evaluation Test Plan (as revised)
8462.ADV.00	Familiar Driver Evaluation Test Plan
8463.ADV.00	Dynamic Route Guidance - Yoked Driver Study Evaluation Test Plan

1.5 Report Organization

An introduction is provided in Section 1. Section 2 discusses the purpose of the paper, while Section 3 presents detailed findings, including subsections that cover background, methodology, key assumptions and constraints, and detailed discussions of data collection procedures and instruments. Section 4 provides the report summary and a compendium of the lessons learned.

2.0 PURPOSE

Every focused test of an implemented system requires maintenance of a systematic schedule and procedure for gathering test data. The ability to assess the validity of hypotheses about system performance and capabilities depends on these data being collected consistent with the specifications established in the evaluation test plans. Such specifications were established for the ***ADVANCE*** targeted deployment during numerous working sessions involving the evaluators and a team from Booz ●Allen & Hamilton, the FHWA contractor tasked with developing the evaluation plan for the targeted deployment. Because of the extremely tight time frame in which the various tests could be conducted, it was imperative that the means and procedures established for data collection be as free from delay and deviation as humanly possible. This report describes these means and procedures, both those adopted from the beginning and those for which necessity arose as tests progressed. It highlights methods which worked especially well and those which were found to be in need of adjustment; it also discusses the workability of those adjustments. The report is intended as an informal guide for *tactical* planners of future ITS deployments.

3.0 METHODOLOGY AND FINDINGS

3.1 Background

Deployment of new ITS technology demands verification that the purposes of the deployment have been achieved and that *results* of development and deployment have been commensurate with *resources expended.* The original planning for the ***ADVANCE*** deployment called for compilation throughout the expected two-year project lifetime of a large evaluation database that would have provided the basis for broadly informative and reliable tests of the various features of the project's systems and subsystems with respect to their capability to perform their stipulated missions.

With the re-sizing of the project to a smaller, targeted deployment, plans for assembling an evaluation database changed only in scope: although sample sizes and the number of data points were significantly diminished, it was still possible to collect adequate data to inform other field operational tests about expected performance of and user response to similar system deployments. This philosophy motivated the developers of the ***ADVANCE*** evaluation plan, in concert with the evaluators, to devote considerable attention to defining the objectives and resources necessary to conduct useful tests, then to deriving a feasible schedule under known time constraints for conducting all needed field activities. Thus, the ten evaluation test plans that were ultimately prepared for the field activities identified, as applicable,

1) the data to be collected and the procedure for its collection,
2) the hypotheses about system performance to be tested using these data,
3) the chronological window(s) (calendar dates) during which data would be collected, and
4) the number of vehicles, hours and drivers required daily to perform the test procedure.

Upon finalization of these plans, it was found that the schedule for all 10 tests admitted virtually no slack with respect to any of the parameters listed above in (4) if there was to be any hope of completing all field tests prior to the mandatory complete de-installation of the in-vehicle navigation units by the end of the calendar year.

3.2 Methodology

Field testing was conducted as described below in support of performance evaluation for each of three major ***ADVANCE*** system features.

1) <u>Purpose</u>: to evaluate the performance of the components of the Traffic-Related Functions (TRF) subsystem and the relative usefulness of probe-equipped vehicles vs. in-pavement loop detectors in providing real-time traffic data.

Procedure: The seven interrelated TRF field tests, managed by the University of Illinois at Chicago Urban Transportation Center (UIC-UTC) faculty, used paid drivers operating up to 15 ***ADVANCE*** system-equipped vehicles four days per week (Monday-Thursday). The vehicles were driven along predetermined routes for which their traversal times for each link were recorded at the TIC, along with arterial loop detector data. These were analyzed to determine the performance of key TRF components, including fusion of data received from probes and detectors into a travel time prediction algorithm; construction of both the default static forecasts and the on-line dynamic forecasts; estimation of the number and frequency of probe traversals required for reliable travel time updates; and the relationship among vehicles' travel times on a link as a function of turning movement and directionality. The data collection phase of the TRF evaluation began on June 5, 1995, and was completed on August 25, 1995.

2) Purpose: to determine whether, and to what extent, dynamic route guidance (DRG), as implemented in the ***ADVANCE*** system, can significantly improve travel times for drivers.

Procedure: This test had two central facets--yoked-driver (YD) timing and incident detection (ID) timeliness. In the yoked driver (DRG/YD) tests, triads of equipped vehicles operated by paid drivers were driven at approximately identical start times between a preselected origin and destination. Two members of each triad followed routes planned and updated in real time through the communications link with the TIC, while the other followed a fixed (or static) route defined by the in-vehicle navigation unit, using only its embedded map and travel time data (i.e., no TIC communications). Two dynamically guided vehicles were used because of the high risk and high cost (to the test) of probe-reporting failures. Up to 18 equipped vehicles acting as probes departed ahead of this pair along alternative routes between each planned origin and destination to provide frequent travel time updates to the TIC. The objective was to determine whether and how frequently the members of the pair that had full communication were given a route that was different from that provided by static guidance only *and* that saved time relative to the static route, or at least received a different routing to indicate the potential for time-saving benefit in other, similar circumstances. These tests, managed by faculty of Northwestern University Transportation Center (NUTC) and conducted by drivers hired by the university, were conducted weekdays and early evenings throughout the month of September 1995.

In the incident detection (ID) evaluation, prestaged and roving field vehicles from a deployed fleet of up to 12 were dispatched in real time to the scene of either a reported incident or a known, actual (or simulated) construction delay. If an actual delay condition was found, these probe-equipped vehicles traversed the affected area repeatedly to measure travel times. Later, the vehicles returned to the incident sites to record travel times under normal conditions. The reliability of the algorithm that identifies construction and incident delays by means of loop detector data and data fusion was also evaluated with data collected from these traversals. Tests were conducted by NUTC during weekday periods of recurrent, non-recurrent, and incident-related congestion (both naturally occurring incidents and staged incidents were used) during summer and autumn, 1995.

3) Purpose: to provide drivers familiar with the ***ADVANCE*** test area with an opportunity to use the ***ADVANCE*** system in their normal driving behavior for a relatively extended period of time. It was expected that these drivers could provide a useful perspective on the characteristics and performance of the ***ADVANCE*** system and help guide the design and development of future advanced traffic information system (ATIS) services.

Procedure: This series of tests began in late July 1995, with the most intense activity occurring from October through early December 1995. The tests made use of families living in the test area that had volunteered to drive ***ADVANCE***-equipped, project-supplied vehicles for a two-week period. These volunteer drivers completed both baseline and post-test surveys and maintained drivers' logs that noted malfunctions, problems, reroutes, and their responses to these. Subsequently, 30 percent of these drivers participated in focus groups that examined their experiences and reactions. This test and the follow-on focus groups were managed by Northwestern University.

It was important to insure that all testing for elements (1) and (2) above successfully retrieved all the needed data from each link traversal, and that this data was being captured and retained at the TIC. It was especially critical during the test period before early August, when project vehicles did not have operative memory-card systems as data backups. A TIC probe report tracking process was created for display as a window in the TIC console, and a report tracking check-sheet was used to assure that each vehicle (identified by its ***ADVANCE*** in-vehicle modem ID) involved in a field test was actively transmitting its traversal data. Any unexpected drop-outs in reports received from a particular vehicle (i.e., no check marks in a given column for consecutive 5-minute periods when the driver was known not to.be on break) triggered a call by test monitors in the TIC to the cellular phone in that vehicle to inquire if the driver had noted any problems. At times, the communication function of the ***ADVANCE*** unit in that vehicle would deteriorate and the system in the vehicle had to be reset. Other specific data recording instruments and problems overcome will be discussed in Sections 3.5 through 3.7 in the context of specific test experiences.

3.3 Key Assumptions and Constraints

3.3.1 Availability of Paid Drivers--TRF Field Tests

During the late spring of 1995, paid drivers were recruited by UIC-UTC to conduct a variety of data collection activities over a twelve-week period through the summer. A number of unusual circumstances made the process of recruitment less than routine. Many of these problems may not be encountered by other field operational tests, but it should be recognized that unexpected situations are likely to occur whenever paid staff must be procured on relatively short notice.

First, there was initial uncertainty about the limits of access to probe vehicles by the paid drivers. As the ***ADVANCE*** office is not readily accessible by public transit that would have enabled the paid drivers to arrive and depart conveniently for their duty hours (noon until 8:00 pm), the Evaluation Test Plans for the TRF analyses specified that some drivers might be taking the vehicle they drove each day home overnight. It was assumed that the Project Manager would employ discretion in releasing the vehicles, requiring at minimum that a garage be available for housing the vehicle overnight. The first several weeks of recruiting were conducted with expectation of the vehicles' overnight availability. When it was made clear that this option could not be enabled for a variety of reasons pertaining to vehicle ownership and insurance stipulations, several recruits with access problems had to leave the driver pool.

The age limits of the drivers was also not clearly established from the beginning. Since work was being conducted through the Illinois Universities Transportation Research Consortium, there was a desire to involve students in the data collection phase. Many of the students being recruited were under 25 years of age, and the indication a week prior to the commencement of driving was that the insurer preferred drivers to be a minimum of 25 years of age. This situation was clarified and younger drivers (21 and older) were permitted.

The last uncertainty related to the insurance liability. The project required drivers participating in the ***ADVANCE*** tests to meet certain insurance requirements. During the driver recruitment phase, it was the recommendation that paid drivers provide their own insurance. This option would have proved difficult for a number of potential drivers who did not own an automobile. Ultimately, the project office assumed the insurance coverage cost for the paid drivers and this ceased to be a problem before driving began.

Many problems arose because of the time limitations in getting all particulars finalized. Included in these particulars was the question of driver compensation. The University of Illinois at Chicago has long-established wage rates for student employees, in this case the vehicle drivers. It was considered necessary and appropriate to pay the drivers more than the very minimal levels dictated by university schedules in that the level of anticipated effort was well beyond what the university rate suggested. Data collection was well underway before this internal university matter was resolved.

There was also a minor problem with the required state check on driving records. This screening identified some recruited drivers with records which, under the limitations of the insurance liability provisions, would have precluded them from driving. While there was no quarrel with this requirement, it disqualified one person who had been counted on to both drive and be a key field worker. A graduate student in his forties, he had spent several years in Europe and was unaware that an unresolved dispute with the licensing office remained on his record. This experience suggested that, for any field test, driving records need to be checked as early as possible so that disagreements can be resolved before driving begins.

3.3.2 Availability and Deployment of Paid Drivers--ID and DRG/YD Field Tests

The majority of paid drivers who were in the field for conducting the yoked driver and incident detection tests were hired by the Northwestern University's Test Manager from respondents to a "help wanted" ad placed in a daily paper serving Chicago suburbs in the ***ADVANCE*** test area. Selection was based on an interview and prior driving experience. A few of the other drivers selected were personal acquaintances of the Test Manager or friends of the interviewed drivers. One driver responded to an ad placed at a community college located near the TIC. A few drivers came to the Project Office from off the street, having seen the newspaper ad or obtained word-of-mouth information, and were hired because positions were available. In general, these drivers were not as successful as the pre-screened drivers in following test protocol. A lesson learned is that hiring should be done based on conduct of an interview a few weeks before the start of the test.

These drivers were not college students, but unemployed and underemployed workers ranging from 21 to nearly 80 years of age who had a wide range of prior job experiences. Most were mature, interested in the work and anxious for the pay. As a result, the experiences with the DRG and ID paid drivers were very positive. Most drivers enjoyed the test and were very conscientious in arriving to work on time, filling out forms, and observing test protocols. Many of the drivers remained available for the duration of the field testing period, even though there was a month or more between the last two test periods.

Each day drivers reported to work at the Project Office, they were required to sign a waiver limiting the liability of the ***ADVANCE*** project for any accident which happened when they were on duty in the field. However, the language of this waiver was legalistic and not well understood by most drivers. Early in the test process, several of the older, more experienced drivers became quite concerned about the liability risks they faced in their daily work as vaguely defined by this waiver.

This became a topic of discussion among the group of drivers and ultimately resulted in several of the older, more experienced, and more reliable drivers quitting because the perceived risk was unacceptable. To preclude loss of more drivers, the Northwestern team arranged for the university's Risk Management Office to conduct a detailed review of insurance coverage provided to drivers in this test. The review made clear that the drivers were protected by three levels of insurance: the university's own insurance (as Northwestern was the employer of record); insurance carried by the Illinois Universities Transportation Research Consortium; and the policy carried by the ***ADVANCE*** Project Office. The risk managers determined that drivers were amply covered--a point the waiver form failed to make clear, and thus gave rise to the perception of hazard by the more senior drivers.

A lesson learned in the above experience is that persons hired for temporary driving jobs need to be provided with specific insurance coverage to limit their risks. Some have little or no coverage of their own, and those drivers most willing to ignore these risks are generally found to be the most impecunious and least able to protect their financial interests. Drivers with adequate personal resources--often the most responsible employees--were most likely to understand the risk and, without the requisite protection, most likely to avoid it by not continuing in their position. In addition to providing adequate insurance coverage, a test manager can further improve employer-employee relations by supplying workers *understandable* information on the actual nature of risks to which they will be exposed on the job each day.

3.3.3 Availability of Project Vehicles

As scoped, some of the evaluation tests scheduled to begin in August required up to 22 vehicles to be in the field at any one time. Conduct of routine maintenance combined with the occasional necessity of unplanned repairs dictated that the pool of equipped vehicles at the project office exceed this requirement by at least two vehicles. At the outset of testing in June, only 15 to 18 equipped vehicles were fully under the project's control. The Evaluation Manager secured eight additional vehicles in mid-July through a rental agreement, such that the project "motor pool" had sufficient change-out flexibility by the commencement of the most resource-intensive tests to enable all tests to be conducted with full vehicle complement. Also in late August, six additional vehicles were loaned by the Ford Motor Co. to the project for use in the field tests. Thus, ***ADVANCE*** reached the full population of 30 fully-deployable vehicles about halfway through the field testing period. These 30 vehicles remained in service from late summer to the completion of field testing on December 14. A lesson learned is the need to ensure before testing begins that the daily availability of test vehicles matches the resource requirements of the test(s) to be run on that day.

3.4 Route and Staging Area Requirements

3.4.1 TRF Evaluation

The objective of paid driver field data collection in support of the TRF evaluation was to have drivers perform a series of structured driving activities over a route defined by a sequence of links. After the completion of each route, the drivers passed through a staging area where they received further instructions. The problems encountered in selecting the staging area and the route are discussed in this section.

3.4.1.1 Characteristics of the Staging Area.

In order to properly coordinate driving activity a staging area was necessary. The staging area needed to be close to the route (in distance and travel time) and of sufficient size that several probe vehicles could be parked at one time for short durations. The ideal staging area would be a quiet street just off the main route where it would be possible to turn around safely and proceed back to the route. A potential staging area found near a school, where making the loop turn to proceed back to the route would have been very easy, could not be used because the red time on the signal getting back to the main arterial on the route was approximately two minutes, while the green time was less than ten seconds. This meant that the potential loss of two minutes on each route at just one intersection, cumulated over the entire day, would have created a long down time. More significantly, vehicles would have been dispatched from the staging area at random intervals, many of which were less than thirty seconds. Most of the randomly dispatched vehicles would be stopped at the two-minute red light, causing a severe clustering of vehicles. This problem was also found to exist elsewhere, and resulted in eliminating several possible staging areas.

Two principal staging areas were finally selected, one near a cul-de-sac with small office buildings and the other in a residential area. Research staff notified police officials in the municipality where tests were being conducted, and the law-enforcement community was made well aware of activities beforehand. Nevertheless, concerned citizens called the police near both staging areas. While there were no complaints from the businesses near the cul-de-sac and while most of the residents near the other staging area were curious and, after being briefed about the work and its purpose, very supportive of it, the members of one household expressed a strong desire for tests to be conducted elsewhere. Drivers were instructed to comply with the speed limit in the residential area. In fact, they drove slower than the other vehicles on the street, but the additional traffic was not welcomed by some households. When activities were relocated to another residential staging area where approval of the neighbors in the immediate area was obtained in advance, yet another unhappy home owner was encountered. His reaction was prompted by the presence of technicians who were called to check a few vehicles that were having problems with their mobile navigation assistants (MNAs).

The home owner objected to the conduct of such testing and repair on the street nearby. When the repairs were subsequently conducted in an off-street open area away from homes, complaints ceased. In general, complications cited above were resolved without additional problems.

3.4.1.2 Characteristics of the Route

Several factors needed to be considered in defining the route used in the analyses. The route had to be sufficiently short so that a high density of vehicular coverage could be achieved. There were a variety of tests to be performed and each had its own requirements. The density of coverage could be varied by using different fleet sizes. The largest number of probe vehicles necessary was fifteen. These probe vehicles needed to travel a route which included a variety of link types, loop detectors for signal actuation, and detectors for volume and occupancy data. The arterial selected (Illinois Route 68) had signal actuation detectors at all of the key intersections, but the detectors recording volume and occupancy information did not provide coverage which would have been considered optimal. For example, it would have been desirable to have detectors collecting volume and occupancy data for two sequential or at least closely-separated blocks along the same roadway to permit link-to-link correlation of data. It was found that routes could be driven which passed over three ***total*** pairs (one detector per direction at three discrete locations) of detectors, but no two paired sets were in the same direction on ***the same street*** along any routes.

Taking into consideration the elements described above, the actual choices were very limited. Some prospective routes were very long, not in distance but in travel time. For example, the link on the selected major arterial just east of Illinois Route 21 looked very promising, but during the peak period was so congested that it typically required more than five minutes to complete just this one link. The other problem with this link was that there was not a safe place to turn the vehicles around.

Approximately 60,000 miles were driven in urban traffic, and driver safety was a key consideration. It was known that there would be hundreds of routes driven each day. There was to be a basic route and another for conducting tests on turning relationships. The initial expectation was that a selection would be made from several.altematives. The reality was that it was not possible to identify a route which met all expectations. Thus, the process of choosing a route ultimately eliminated, for one or more of the reasons discussed above, all but the route that was selected. With a much larger driving fleet and a smaller range of tests, a broader final choice of routes would have been more likely.

In summary, the routes driven and the staging areas selected--a selection significantly constrained by real-world circumstances in the study area--nevertheless provided a good environment to conduct the driving tests. The route included numerous turns and passed through commercial and residential areas. It included two-lane and four-lane facilities and a range of traffic signals and stop signs. Ultimately a very large and useful data set of over 50,000 link reports was produced from probe vehicle traversals and detector data along this route.

3.4.2 DRG/YD and ID Evaluations

A typical day in the TIC during the DRG/YD and ID tests began at 2:00 PM. Drivers signed in and were assigned vehicles for the yoked test or chose a vehicle for the ID test. Route assignments and any other special messages or instructions were given. Generally the drivers were on the road by 2:30 Vehicles were tracked and drivers were called if MNA reports were not received every ten minutes. When called, drivers were asked about their MNA and traffic conditions. A decision was made in the TIC about the likelihood of a probe reporting malfunction and drivers were then given instructions to reset the MNA if there appeared to be a malfunction or to standby otherwise.

For the yoked driver test, probe vehicle drivers were divided into six teams of two or usually three (dependent on driver or vehicle availability), plus two dynamic yoked vehicles and a static yoked vehicle. Each driver was given a booklet of route plans which showed each OD pair, the staging area for each run, and the route to be taken. Captains were appointed for each team; each of these had a form which listed dispatch times for each team at each OD pair. A field manager was appointed for the test to be present on-site to start the test for each OD pair assigned, and to oversee the dispatching of probe and yoked vehicles. The field manager used a watch synchronized with the TIC clock to determine the time for each test start. This time was also recorded in the TIC by the test manager. The field manager and all drivers were in contact with the TIC by cellular telephone.

When each driver finished a run, he or she called the TIC and the finish time was recorded. Precise recording of the finish time was not critical for the test; however early in the process it provided feedback on whether the route start times and lengths were appropriate. For example, yoked vehicles arriving well before some of the probe vehicles would be an indication that the probe vehicle launch time may have been designed to start too late. Calling in the finish time also established a communication channel between each driver and the test manager and served to improve driver performance and consistency.

Staging areas for the DRG tests were different from those for the TRF tests in that 21 or more vehicles were involved. This required larger staging areas and, in some cases, advance permission from property owners to assure that the ***ADVANCE*** vehicles would be accepted. Because of the large number of drivers, it was also especially desirable to pick a staging area where drivers could make stops, acquire drinks, go to the washroom, and make telephone calls. Vehicles were staged in parking lots of forest preserves, schools, and shopping centers of various sizes. In the case of school lots, prior arrangements for use were especially important in that the timing of yoked driver tests on occasion placed 21 vehicles in a school lot while the school was still in session.

The choice of staging areas had a direct effect on the actual routing of yoked vehicles in the case of certain OD pairs. For example, when vehicles were staged in a large shopping center at the intersection of two major arterials, drivers might be routed into traffic by one of three or four exits separated by some considerable distance. In at least one case, some of the routes followed arterial streets at the edge of the sub-network in which the OD pairs were laid out, and included local "collector" links not adequately covered by probe vehicle travel time reports. This suggests a need for careful on-scene supervision to understand exactly where drivers are staging and what routes they are following in and out of staging areas.

For the ID test, the computer log file from Northwest Central Dispatch (NWCD), a computer-aided police, fire and ambulance dispatch center serving six communities in the middle of the ***ADVANCE*** test area, was monitored in the TIC to identify incidents deemed appropriate to observe. When an accident with injuries or accident with property damage occurred in the vicinity of the driver assignments for the day, the test manger called the appropriate driver, asked for his or her location and, if they were close enough, sent the driver to the incident location. The test manager then fielded calls about the existence of the incident, and the nature and location of the incident if it was sighted. The test manager then gave the drivers further instructions about the traversals they were to make. It was helpful to listen to the NWCD dispatcher's band on the radio because often a more specific location or description of the incident was available. A log was kept of each incident observed, both in the TIC and by the driver. At 6:45 p.m., drivers were instructed to call the TIC to receive directions about finishing their routes and returning to the TIC. Drivers returned to the TIC between 7:15 and 7:30. Upon their return, the test manager made sure appropriate forms were submitted.

3.5 Data Collection Logs and Unusual Occurrences

3.5.1 Real-Time Data Retrieval Tracking

Both the evaluators and the evaluation manager maintained procedures to minimize data loss while field tests were in progress. A set of forms for real-time "hard copy" recording of information was developed to assure post-test capability to trace the time and cause of specific events having the potential to disrupt or even invalidate data collection. A tracking check-sheet was used to assure that probe reports from vehicles known to be active were arriving at the TIC at acceptably short intervals (Attachment A). If an automated report from a given vehicle had not been received at the TIC for 7 or 8 minutes, its driver was contacted by cellular phone to determine if a problem had developed with its communications. The tracking form was supplemented, given vehicular or system problems, by a "problems" log book entry for that day, of which a typical example is shown below.

SEPTEMBER 5
Yoked driver fixed-route runs.

The Aerostar reported that the dead-reckoning arrow and the GPS circle kept drifting apart (arrow got behind), indicative of an MNA system crash. Radio communications with this vehicle were maintained throughout the period, however (note--GPS circle imprecision is frequently associated with an imminent communications failure).

Loss of differential GPS and problems with display head screen "freezing" with an unchanging image persist with Grand Am (modem # 42) and Continental (modem # 9). Continental was fixed on-site by Motorola staff in the field; however, the Grand Am had to be returned to Motorola for display head replacement. After these fixes, no additional problems were reported.

Paid drivers for the TRF tests also maintained daily running logs, of which an example is shown as Attachment B. These logs were used to record specific run durations as well as to document unusual occurrences such as railroad grade crossing delays, signal cycle failures due to congestion, or other events that precluded completion of a route according to a stipulated test procedure. They also indicated when the drivers believed they had lost functionality of the in-vehicle navigation unit or were otherwise out of communication with the TIC.

Yoked vehicles in the DRG/YD tests had data forms to show the routes they had taken and any reroutes. The test start and.finish times for each vehicle were also recorded on a form in the TIC (Attachment C). For the ID test, the data forms used were a reconnaissance form and incident form used by drivers and two forms used at the TIC. The reconnaissance form was used by drivers to record the location, date and roadway impacts of construction activity. The incident form was used to record the date, type and location of incidents which were observed by drivers. Incident Data and Construction Data forms (Attachments D and E) were used by the Test Manager in the TIC to record, respectively, the NWCD log number, vehicles assigned, type, date and time of incidents observed; and dates and link locations of planned construction lane closures. A form which listed vehicles, drivers and assignments was also completed in the TIC for both the DRG and ID tests.

A D V A N C E

Vehicle Tracking Matrix

Time	MODEM ID																														#
	9	A	B	D	E	10	11	13	14	15	16	17	19	1A	1B	28	2B	3E	41	42	44	45	4B	50	52	54	57	59	5A	5C	Rpts
5:35 PM																															
5:40 PM																															
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6:40 PM																															
6:45 PM																															
6:50 PM																															
6:55 PM																															
7:00 PM																															

		#	Vehicle ID	#	Vehicle ID
9	Continental--Green	16	Continental 44M284	44	Continental 31M189
A	Jimmy	17	Green Mercedes	45	Grand Am OAT 839
B	Bonneville	19	Grand Am DGT 670	4B	Continental 31M193
D	Silver Mercedes	1A	Seville	50	Grand Am VWL 277
E	Lexus	1B	Olds 98	52	Continental 44M516
10	Lumina APV	28	Grand Am PJA 266	54	Continental 33M688
11	Towncar	2B	Sable	57	Windstar
13	Volvo	3E	Grand Am VXW456	59	Grand Am COV 316
14	Tan Accord	41	Aerostar	5A	Continental 44M279
15	Black Accord	42	Grand Am OAT 856	5C	Grand Am VXT 276

Attachment A

Date:___________________ Recorder:____________

Test Name:______________ Page:- - - O f - - - -

Driver Lag

Name: Vehicle make: Volvo Vehicle ID: 13

Date: 7/6/95 Temperature: 78° Sunny - mostly Cloudy - later - - Rain (circle one)

Tire Pressure: Gas: Other Gauges:

Codes to Simplify Comments

1 Cycle failure	4. train	7. MNA frozen
2 left turn blocks traffic	5. constriction	8. off route (staging, turn-around)
3. thru move blocks traffic	6. MNA off/question	9. rain/weather

Begin Time	Location	Comments	End Time
12:58	Staging area	reboot - intermitant differential on way to site	
1:02	"	reboot again, and a 3rd time at 1:05 4th try 1:06 - Motorola came to fix problem	
1:26 —	Drove	with A. L. in town car	2:53
2:57	Started	in Volvo	
2:59	West of Schoenbeck	1 due to rt. lane closure	3:00
3:04	4	1 (left turn lane)	3:06
3:24	9	Accident blocking rt lane	
?	Bk	Lunch Break	4:11
5:04	12	1 (left turn lane)	5:06
5:14	7	~~1 traffic blocked north until Strong~~ 1 southbound traffic blocked up from Milwaukee until Strong	?
5:22	9	1	5:25
5:34	3	4	5:34
5:37	7	1 Southbound traffic backed up from Milwaukee to Strong	5:44
5:46	9	1	?
6:15	Bk	break	6:24

• See Route Mad for Location Key

ADVANCE Project Office I-708
Field Manager Cell Phone 1-

Attachment B

DRG Test Run Completion times

O-D Pair: 3 Date: 9-12 Start time: 6:05

Run Number	Vehicle Number & Description	Driver Name	Run End Time	
1	1 Bonneville /08/0021	Ernie	6:36	
	2 Cadillac/1A/0016	Ken N	6:41	
	3 Oldsmobile/1B/0013	Steve D	6:42	
2	1 GAm red/3E/0032	Steve R	6:35	
	2 TownCar red/11/0025	Herman	6:42	
	3 GAm Red/5C/0033	Aaron	6:41	
3	1 Lumina/10/0017	Peggy	6:37	
	2 Volvo/13/0022	Bob	6:38	
	3 Mercedes green/17/0011	Bill D	6:36	
4	1 GAm white/19/0031	Joe K	6:39	
	2 GAm red/28/0029	Jason	6:39	
	3 Aerostar/41/0019	Tom K	6:40	
5	1 GAm green/42/0034	Joan	6:39	
	2 GAm red/45/0035	George	6:40	
	3 GAm green/50/0028	Anne	6:51	
6	1 Windstar/57/0020	Marie	6:37	
	2 Jimmy/0A/0024	Wally	6:39	
	3 GAm red/59/0030	Warren	6:36	
Yoked	dynamic 1 15/0014 Honda black	Lance/Kathy	6:45	
	dynamic 2 0E/0002 Lexus	Holly/JC	6:51	O
	static 19/0015 Honda van	Mike/Irene	6:48	

ADVANCE Dynamic Route Guidance Test August 24, 1995

Attachment C

Incident Data Summary

NU ADVANCE Incident Number: ____1_____________

Date of Incident: _______8/9/95________________

NWCD Information:

Incident Number(s) AHP9534421 , AHP9504539

Incident Type ___________________________

Start Time: _______________ Clear Time 4:26

Location at Intersection

Intersection Name _____________________________________

Incident Link and Direction (Road Name, Direction, Entering/Leaving Intersection):

____

Location on Roadway

Roadway Name Rand

Approx. Location

Between Wilke and Hintz

Distsance 15ft. and direction SE from location Wilke

Impacted Links/Roads (if known) ____

Links Traversed: Rand, Arlington Heights to Dundee, both diections

Vehicles Assigned During Incident:

Vehicle: 41	On Screen Time: 3:52	Depart Time: 4:43
Vehicle: A	On Screen Time: 4:02	Depart Time: 4:45
Vehicle: _______	On Screen Time: _______	Depart Time: __________

Follow up vehicle assignment(s) : Note: Search all same links during 2pm-7pm time period of days we worked.

Date: 8/21	Vehicle(s): 41, 10, 15, 2B
Date: 8/25	Vehicle(s): 5C, 59
Date: 8/23	Vehicle(s): A, 1B
Date: 8/24	Vehicle(s): 23, 57, 2B
Date: 11/15	Vehicle(s): 16

General Comments: Blocked NWB & SEB lanes

Attachment D

Construction Data Summary

NU ADVANCE Construction Number : 2

Construction Periods (Yes/ No)

Week of August 7th Y
Week of August 21st Y
Week of November 6th N
Week of November 13th N
Week of Novembe 20th N

Primary Roadway:

Roadway Name: Busse
Approx. Location: Between Chariot and Howard

Seconday Roadway:

Roadway Name: Oakton
Approx. Location: Between Crossen and Higgins

Impacted Links/Roads (if known): Busse, Algonquin to Lanmeir, both dicections, Oakton Lively to Elmhurst, both directions

Description of blockage: Lane closures for patching, ER, WB&SB = 1 , N=2

Vehicles Assigned During Construction:

Date: 8/19 Vehicle(s): 9, 57, 41, 11, B 8/24: A, 17, 15
Date: 8/10 Vehicle(s): 17, 41, 57, A 8/25: 15, A, D, 15, 57
Date: 8/21 Vehicle(s): A, 9, 17, 57
Date: 8/22 Vehicle(s): 59, 9, 15, 41, A
Date: 8/23 Vehicle(s): 50, 14, 2B, 41, 15

Assigned Vehicles During Non-Construction:

Date: 11/17 Vehicle(s): 5A, 16, 9, 52, 32
Date: 11/14 Vehicle(s): 9
Date: 11/15 Vehicle(s): B, 5A
Date: 11/16 Vehicle(s): 14

General Comments:

Attachment E

3.5.2 Unusual Occurrences

The Chicago region experienced in 1995 one of its hottest summers on record. Although the discomfort of paid drivers could be alleviated by using air-conditioned vehicles, some of the electronic components of the in-vehicle systems, specifically the CD-ROM drives, were mounted in locations (such as the trunk) that were not cooled from the passenger compartment As a result, these drives experienced functional difficulties attributed largely to the high-temperature environment in the trunks of some of the vehicles These components were frequently exposed to temperatures in excess of 65 degrees Celsius, although the drives themselves were not certified for functioning above 60 degrees Late in June, all test vehicles received replacement drives that operated successfully to at least 65 degrees Celsius, and systematic drive failure and degradation of MNA performance ceased thereafter when all reasonable precautions were taken to keep the trunks cool--for example, parking cars in shaded areas and opening trunk lids during breaks.

3.4 Data Capture and Archiving

3.6.1 Daily Test Logs

The complete set of daily logs of all electronic reports received by and dispatched from the TIC for each test day (covering the period approximately 6 a.m. to midnight)--MNA reports, loop detector reports, NWCD incident reports, TRF messages (travel time projections) and DGPS corrections--were retained on disk storage media on the TIC computer Early on the morning of the next day, a process was automatically initiated to compress these logs into a tar-gz file, then transmit the compressed file via a T3 telecommunications link to a data server/host at Argonne National Laboratory. The ANL server then automatically uncompressed the tar file and wrote the complete set of logs for the preceding day to a password-protected data page as the files for the current calendar date (the data page entries for "September 22" would all be September 21 field data). Time stamps were retained for all log records, permitting evaluators to re-create project vehicle routes, route sequences, and contingent events according to a precise chronology. Data on the ANL server were made available by Internet FTP or HTTP links to remote locations where the evaluators conducted downloading and analysis.

3.6.2 Memory Card Files

Every Friday during field tests, the PCMCIA cards containing link traversal data recorded on board each vehicle were removed from the project vehicle MNA display heads by Project Office staff and downloaded by card reader. None of these cards ever exceeded or even approached its 2 MB (formatted to 1.44 MB) capacity over a week of testing In addition to time-stamped link traversals, the cards also recorded vehicle position at two-second intervals as referenced to a map grid developed by Motorola. These binary-coded files were converted to ASCII at the TIC by a process supplied by the TIC, then both the original binary and new ASCII files were transmitted electronically to ANL. The latter were installed weekly on the data page as dated entries in a special subdirectory.

Although the "memory card" were not available in vehicles until after field evaluations had begun (their performance not verified as adequate until the introduction of version 1.5.6.0 of ***ADVANCE*** in mid-July), it was apparent that their contribution to the data collection effort would be essential. Occasional TIC process failures and instability and the occasional MNA system crash prevented the daily log file archiving and compression process to function properly. Although such occurrences were rare, there were at least two days of very intensive field data collection in which the entire day's worth of time-stamped link traversal records would have been lost had not memory cards been available and functioning in the project vehicles, A lesson learned here is to have a backup automatic data retrieval system in place for all critical field testing.

3.7 Familiar Driver Data Collection Instruments

Continuous monitoring of vehicle movements was neither necessary nor desirable during the two-week periods in which drivers familiar with the roads system in the ***ADVANCE*** test area used MNA-equipped project vehicles based at their respective residences. However, these drivers were asked to complete three different types of information recording instruments as part of their agreement to participate in the program:

1) a baseline survey, filled out prior to receiving a project vehicle, providing the characteristics, driving experience, and previous use of traffic information services (e.g., radio, cellular phone) of each participating driver (up to 2) in the household;

2) re-route logs, to be filled out during the two-week period at any time that a driver decided not to use an ***ADVANCE*** system-provided route or received an alternative routing option while following an MNA-preplanned route; and

3) an exit survey, recording each driver's overall end-of-test response to and reactions about the two-week route guidance experience.

Obtaining the completed first instrument was quite trivial in that no household would be issued a vehicle without it. Thus, data capture was 100 percent. Of 80 households participating, 74 completed at least one re-route log, while a few completed as many as 20. Obviously, there was no way to verify that all re-routes were recorded by each of the 74, or that no reroutes were actually presented to or undertaken by the remaining six. Finally, 78 of the 80 households returned the exit survey.

For this last instrument, the two principal difficulties in achieving complete data capture were that 1) the participants were not required to complete the exit survey when they returned their vehicles to the Project Office (but were given three days to do so and return the completed survey by postage-paid envelope supplied by ***ADVANCE*** and 2) there was no "suasion" applicable for non-return. Several households had to be reminded to return the completed surveys, and in some eight cases an official letter was sent advising them that survey completion was part of their participation agreement. Even so, two households that were repeatedly contacted did not respond. Moreover, those surveys that were returned revealed that, in many households, only one member of a preselected two-driver household had actually driven the vehicle and filled out the survey, even though both drivers might have completed the baseline instrument. A lesson learned is that, without some inclusion in the pre-test agreement for "volunteer" drivers of an explicit reward for timely completion of or penalty for non-response to survey instruments, post-test survey response rate will fall short of 100 percent. Another lesson is that any target set for the absolute number of participant driver surveys to be entered in the database should not assume that in all pre-qualified two-driver households both drivers will drive the vehicle, unless instructions and incentives are offered to assure that both drivers will participate in the test. Even if all households were selected as two-driver units, no more than 1.4 drivers per household should be expected to participate unless special steps are taken to assure each driver uses the vehicle.

4.0 SUMMARY OF LESSONS LEARNED

Each of the ***ADVANCE*** targeted deployment field tests was designed to achieve a specific, focused objective in an environment in which severe constraints on time, personnel and vehicular resources greatly influenced both scoping and execution of the tests. Subsequent ITS deployments facing similar constraints should prepare for successful collection of the desired data base for such deployments by considering the following recommendations that have arisen from lessons learned in the data collection phase of the formal evaluation of ***ADVANCE.***

1. Unexpected situations are likely to occur whenever paid staff must be procured on relatively short notice. Problems will arise because of the time limitations in getting all particulars finalized, especially those relating to liability insurance coverage. *Resolution of insurance issues should be given the highest priority before field testing protocols and schedules are finalized.* In particular,

   a) driving records (violations, outstanding fines, license problems) for *all* participating drivers need to be checked as early as possible so that disagreements with organizations responsible for insurance coverage can be resolved before driving begins; and

   b) persons hired for temporary driving jobs need to be provided with specific insurance coverage to limit their risks. Some have little or no coverage of their own, and those drivers most willing to ignore these risks are generally found to be the most impecunious and least able to protect their financial interests.

2. Hiring of paid drivers for specific tests should be done based on conduct of an interview no later than a few weeks before the start of the test. Other means of recruitment evaluation are likely to prove less satisfactory.

3. Ensure before testing begins that availability of test vehicles will match the resource requirements of the test(s) to be run on any given day; this includes accounting for vehicles scheduled for maintenance and repair.

4. If vehicle staging areas in residential areas are used, it is not likely that all potential objections from neighboring residents can be anticipated and allayed in advance. Nevertheless, prior clearance with local law enforcement and directly-affected institutions (school, shopping areas) is essential for both logistical and diplomatic purposes. Moreover, even after testing begins, there may remain the need for careful on-scene supervision to understand exactly where drivers are staging and what routes they are following in and out

of staging areas.

5. Under the constraints of highly-focused tests that use a limited number of test vehicles, the selection of test routes designed to maximize the spectrum of representative facility types in the area will be similarly constrained. It is likely that the process of choosing a route ultimately will eliminate all but a few candidates. With a much larger driving fleet and a smaller range of tests, a broader choice among routes, possibly with fewer link traversais required per vehicle, would be more likely.

6. Written logs should be maintained to document unusual events during tests: paper trails are vital to attempting after-the-fact diagnoses of operational problems that resulted in lost or corrupted data.

7. Where electronic data collection is used, a backup automatic data retrieval system should be in place for all critical field testing.

8. The pre-test agreement signed by "volunteer" drivers should provide for an explicit reward for timely completion of or penalty for non-response to survey instruments; otherwise, it is almost certain that the post-test survey response rate will fall short of 100 percent of target.

9. The target total response for the absolute number of participant driver surveys to be entered in the database should not assume that in all pre-qualified two-driver households both drivers will drive the vehicle, unless instructions and incentives are offered to assure that both drivers will participate in the test. Even if all households were selected as two-driver units, no more than 1.4 drivers per household should be expected to participate unless special steps are taken to assure each driver uses the vehicle.

10. In retrospect, it was fortuitous for two reasons that the periods of high-intensity vehicular use in the testing schedule (the paid driver tests) generally preceded those of lower-intensity, unsupervised utilization (the familiar driver experiences): (1) virtually all system operational problems were able to be resolved prior to the time period allocated for the most intensive use of vehicles by volunteer (familiar) drivers, and (2) the evaluation thus avoided what might have been undesirable yet inevitable prioritization of limited vehicular resources to one type of test over another when vehicles assigned to a test had to be replaced.

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APPENDIX E

TECHNICAL CHALLENGES IN DEVELOPING ADVANCE

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TECHNICAL CHALLENGES IN DEVELOPING *ADVANCE*

EXECUTIVE SUMMARY

In developing ***ADVANCE*** over the last several years, many lessons were learned and challenges overcome. This report documents the technical challenges that were faced and the lessons learned that could be used by others that are planning to develop similar systems.

The authors of this report were involved in the development of ***ADVANCE*** almost from the start of the project design efforts in 1991. They represent the main designers, developers and integrators of the subsystems of ***ADVANCE.***

Key findings of the report include the following:

- retrofitting of a display unit near the driver in a safe location is difficult due to the deployment zones of the airbags.

- the design of similar systems should be a “bottoms up” approach with functionality added as the capacity of the hardware and the project schedule are defined.

- the technologies used for the in-vehicle unit, although well developed, need further refinement to ensure performance under all climatic conditions.

- when testing the in-vehicle unit, it was found very helpful to have diagnostic tools which captured incoming and outgoing data streams.

- the lack of availability of proprietary information for the in-vehicle unit affected the ability of the system integrators to fully test the system and also caused the integration process to be longer.

- rapid prototyping of similar systems to obtain user feedback on the TIC interface during the design process is recommended.

- where a developer does not write his/her own code, it should be a requirement that they check the code with the coder after it is written to ensure the design has been interpreted correctly.

Despite the challenges noted above and the lessons learned, it is important to note that a fully functioning dynamic in-vehicle navigation system was successfully developed and deployed.

TECHNICAL CHALLENGES IN DEVELOPING *ADVANCE*

TABLE OF CONTENTS

TECHNICAL CHALLENGES IN DEVELOPING ADVANCE

1.0 INTRODUCTION

In developing ***ADVANCE,*** both as a whole and each of its various subsystems, the state of the art of the various technologies was reached. In addition, ***ADVANCE*** was developed using a series of releases with each new release adding additional functionality to the previous one. Thus, each new release of a subsystem had to perform its intended purpose and continue to work with the other subsystems. A further complication was that the development was done by a variety of personnel, from different corporate backgrounds operating in distinct, separated geographical sites. The end result of all this was to create numerous technical challenges in developing ***ADVANCE*** This report documents the technical challenges in developing ***ADVANCE*** by noting what they were, what their impact was and how the challenges were met and overcome. Readers interested in lessons learned on the RF communications system as well as the TRF algorithms should also read these respective reports. This report also documents the achievements that were accomplished in that a dynamic, in-vehicle navigation system was developed and deployed.

1.1 Acronyms and Definitions

Acronyms and definitions are contained in the ***ADVANCE*** System Definition Document #8020.ADV.06. To aid in reading this report, several of the more common terms are defined below.

CATS - Chicago Area Transportation Study, the metropolitan planning organization for the Chicago area.

CD - Compact Disc

COM - RF communications subsystem of ***ADVANCE.***

C-TIC - Corridor - Traffic information Center - the information center that will be used to distribute travel time related information as part of the Gary-Chicago-Milwaukee Corridor project.

Data Fusion (DF) - A TRF algorithm on the TIC. Data Fusion acts as an intermediary between external components and other TRF components. It will screen data received from Closed Loop Signal Systems and probe vehicles and aggregate this with all other on-line data to estimate link travel times for the last five (5) minute interval.

Differential GPS - A correction applied to GPS positioning to improve accuracy.

FHWA - Federal Highway Administration, one of the founding parties. FHWA was responsible for the overall evaluation of the ***ADVANCE*** project.

GPS - Global Positioning System, a government-owned system of 24 earth-orbiting satellites that transmit data to ground-based receivers. GPS provides extremely accurate latitude and longitude ground position in WGS-84 coordinates. However, for U.S. strategic defense reasons, deliberate error(called selective availability) is introduced into the code that is provided for civilian users.

IDOT - Illinois Department of Transportation, one of the founding Parties. IDOT was responsible for providing project management for ***ADVANCE*** and for operating the TIC.

<u>Incident Detection (ID)</u> - The detection at the TIC of activities on the roadway that significantly reduce the capacity of the roadway from the expected capacity at a particular time. The detection may be based on input from probes, fixed detectors, anecdotal sources, and such other data as may be available.

<u>IUTRC</u> - Illinois Universities Transportation Research Consortium, IUTRC is a nonprofit corporation owned by Northwestern University, the University of Illinois at Chicago, the University of Illinois at Urbana-Champaign and the Illinois Institute of Technology.

<u>Link ID</u> - A unique ID that identifies each roadway link.

<u>Memory Cards</u> - A plug-in computer memory card containing prerecorded information. May function as mass storage for onboard navigation systems.

<u>Motorola</u> - One of the founding Parties. Motorola provided the in-vehicle systems as well as the RF communications subsystems.

<u>MNA</u> - Mobile Navigation Assistant, an in-vehicle navigation system designed and built by Motorola that determines vehicle position, performs route planning based on current traffic information, and provides dynamic route guidance information to the driver.

<u>NUTC</u> - Northwestern university Transportation Center. Northwestern University is a member of the IUTRC.

<u>NWCD</u> - NorthWest Central Dispatch, an emergency dispatch service for several of the communities in the ***ADVANCE*** test area.

RF - Radio Frequency.

<u>Short Link</u> - A link which has an approximate travel time of less than two (2) seconds. These short

links are often turn bays or roadways connecting one-way streets separated by a grass median.

SSI - Surface Systems Incorporated, provides weather information.

Static Profile - Static information of the roadway link including day type, link ID and average travel times for a specific time period.

Static Profile Update (SPU) - The process of updating the travel times on a given roadway link in the ***ADVANCE*** test area.

TIC - Traffic Information Center, consisting of the hardware, software, a centralized facility and operations personnel. It communicated to and from probes and external systems.

TRF - Traffic Related Functions, subsystem consisting of data fusion, vehicle dynamics, incident detection and travel time prediction algorithms.

Travel Time - The time it takes to travel from one end of a link to the other.

Travel Time Prediction (TTP) - An algorithm used in the prediction at the TIC of future short term travel times on links to develop future adjustments to the static profiles.

TSC - Traffic Systems Center, operated by IDOT to monitor and control the flow of traffic on expressways within the Chicago area.

UIC - University of lllinois at Chicago. UIC is a member of the IUTRC.

1.2 Authors

The authors of this report were all intimately involved in the development of ***ADVANCE,*** most of whom were involved from the beginning of the design in late 1991. The authors are as follows:

Syd Bowcott

Mr. Bowcott has over 25 years experience in traffic control systems and is the Chief Engineer-ITS Programs for De Leuw, Cather & Company. Educated as a Civil Engineer, he has worked for both the public and private sectors. On ***ADVANCE***, he led the De Leuw, Cather & Company team that functioned as the lead systems engineer and was responsible for system integration. He has worked on ***ADVANCE*** since late 1991.

Ray Makaras

Mr. Makaras was responsible for the design of the RF communications system used in

ADVANCE He also was responsible for installation and maintenance of the Mobile Navigation Assistant (MNA) units in the vehicles.

Pete Nelson

Dr. Nelson is Director of the Artificial Intelligence Laboratory (formerly known as the ITS/IVHS Laboratory) at the University of Illinois at Chicago where he is also an Associate Professor in the Department of Electrical Engineering and Computer Science. He was responsible for leading the TIC software and hardware development effort. Dr. Nelson and his team also contributed to several other areas in the *ADVANCE* project including: requirements analysis, system architecture design and detailed TRF design and implementation. Dr. Nelson began working on what was to become the *ADVANCE* project in the fall of 1990.

Jeff Hochmuth

Mr. Hochmuth is a licensed P.E. and the ITS Technical Coordinator for the Illinois Department of Transportation. He was responsible for managing the operation of the TIC. He also assisted in integration of the various subsystems within *ADVANCE*.

1.3 Intended Audience

The audience for this report is intended to be those that are technically interested in the *ADVANCE* project and have a basic understanding of the *ADVANCE* architecture as well as its goals and objectives.

Researchers, designers, developers and integrators of Intelligent Transportation Systems are expected to benefit from the lessons that were learned in *ADVANCE*

1.4 References

The following reports and documents would be of interest to the reader desiring further information on *ADVANCE:*

System Definition Document - #8020.ADV.06-2.0
Interface Control Specification Document - #8110.ADV.052.0
General Design and Detailed Design Document - #8500/8600.ADV.01

1.5 Report Organization

This report consists of Section 1 which contains the introduction; Section 2 which notes the purpose of the report; Section 3 which presents the methodology and findings of identifying and documenting the technical challenges encountered; and Section 4 which provides the report summary. The appendix contains unresolved comments from reviewers of the report who did not necessarily agree with the authors.

2.0 PURPOSE OF THIS REPORT

This report is intended to provide an historical record of lessons learned from the technical challenges encountered in developing and implementing ***ADVANCE*** and its subsystems. While another report will deal with the integration challenges encountered, this report will deal more with the design challenges encountered, what impact they had and how the challenges were met in providing a successfully functioning system.

It is intended this report will be useful to others that are currently involved in or will be involved in developing sophisticated Intelligent Transportation Systems, particularly those dealing with Advanced Traveler Information Systems.

3.0 METHODOLOGY AND FINDINGS

3.1 Background

Over the course of the development of *ADVANCE* as a system and the development of its various subsystems, numerous technical challenges were encountered. Each of these challenges presented a unique trial that had to be met and overcome before the project could proceed to its successful conclusion. The variety of challenges encountered and how they were overcome is the subject of this report. It is felt that others that are or may be developing similar systems could quite possibly face the same challenges. The experiences of the *ADVANCE* developers could then be of use as to what worked and did not work in overcoming these challenges.

3.2 Methodology

In approaching the development of this report, it was felt necessary to ensure the involvement of staff who had been closely involved in the development of *ADVANCE* as a system and of its various subsystems. This was done by involving senior designers from Motorola, the Department of Electrical Engineering and Computer Science at the University of Illinois at Chicago and De Leuw, Cather.

Once the authors had been selected, one author was assigned responsibility for outlining the report and documenting what he considered the key technical challenges in ***ADVANCE*** This documentation was then circulated to the coauthors and their comments were incorporated into the draft. The challenges documented herein were based on recollections, on memos, on minutes of meetings and on discussions with staff who were not coauthors.

3.3 Key Assumptions and Constraints

The key assumptions and constraints in developing this report are as follows:

- any bias of the coauthors should not affect the final report
- the coauthors had sufficient experience with *ADVANCE* to be able to document the technical challenges

3.4 Findings

The technical challenges that were encountered and how they were overcome on the way to providing a fully functioning system are documented in the following sections. The challenges are grouped according to the particular hardware or software which presented the challenge.

- MNA Installation

Several challenges were encountered with respect to MNA installation. These included:

- Minimal Physical Impact on the Vehicle Appearance-The vehicles used in the project were new vehicles on loan from various manufacturers. They were to be returned to the manufacturer in the condition received. This approach was also necessary since the full deployment of *ADVANCE* would be dependant on individuals "volunteering" use of their vehicles for a period of time after which the MNA units would be removed. Hence, MNA installation was to result in no long- term noticeable effects on the vehicle appearance. This resulted in a variety of approaches being taken to minimize aesthetic damage. These included use of glass mounted RF antennas; use of removable "U" mountings for the GPS antenna (or a magnetic mounting); installation of the CD drive and navigational computer in the trunk; mounting of the compass/gyroscope in the headliner; hiding of wires; and mounting of the display head on an arm either coming off the floor or from the side of the console (as opposed to mounting it off the dash which would have left visible scars). While some elements were common between vehicles with respect to installation, others were not, such as where power was obtained. Hence, each installation was unique and no economies of scale were possible due to the relatively small number of vehicles involved. However, the wide variety of installations would have been useful if full deployment were pursued. Other than convertibles, no vehicle was excluded by type or manufacturer. It is recommended that future installations either, if it is a limited test, use very similar vehicles; or if it is a full scale deployment involving retrofitting, attempt to minimize the number of different types of installations involved in order to achieve economies of scale.

- Safety Issues-Although driver safety is discussed in detail in another paper, one area involving safety is of interest here. This relates to the actual installation of the MNA display head. While a driver's side airbag did not normally create a problem, the deployment envelope of dual airbags does limit where the MNA display head can be mounted. This will continue to be a problem in the future. It dictates a need to customize installations for after market add-ons. In addition, there was a problem in identifying the deployment zone of the airbags. Information was difficult to obtain and recommendations from the vehicle manufacturers tended to be general in nature. All loaned vehicles were outfitted with displays, although some units were not necessarily placed in optimal locations for driver interface.

- MNA Design Criteria

- During the early stages of the project, an ambitious design was defined. This design included provision for such items as a business directory and voice actuated inputs.

Subsequently, due to schedule, technical limitations and budget, the implementation of the design had to be scaled back. This scaling back was facilitated by the design being implemented in incremental releases which built upon its predecessor. That is, features were added only after the preceding release proved to function. Nonetheless, expectations were built up during initial stages of the project for an elaborate system. The lesson learned is that while added functionality must be planned in the initial project stages, the basic unenhanced design should be the focus. This challenge however is a problem that is typical of all complex systems during their development.

- MNA Display Screens

  - Glare-The man-machine interface was provided through a 5.7 inch diagonal, active matrix color liquid crystal display (LCD). The computer received instructions from the driver through button presses to hard keys located on the display housing and through touches to the display screen itself. The original display design used an analog resistive technology to sense the driver's touches. This technology is recognized in the industry as having good response characteristics, however, its viewing surface is also highly reflective. This mirror effect made it unacceptable for use in an automobile application. To ensure good driver response and good visibility in sunlight, the display was redesigned using infrared emitters (IR) (just like a TV remote control) over the LCD and detectors used in place of the analog resistive approach. This technology change offered drivers a far superior information display. As is the case with most display technologies, including cathode ray tubes (CRT), very bright direct sunlight causes degradation in the ability to see the display information.

  - Display Intensity Degradation-Liquid crystal displays typically do not work well in extremely cold temperatures. On cold winter days, with temperatures well below freezing, the display would appear "washed-out" until the unit reached its operating temperature. Because the display used a high voltage back-light behind the LCD panel, the full color intensity was established and maintained within a few minutes-even on the coldest Chicago morning. This was viewed as only being a minor inconvenience.

- MNA Displays

  - Due to technical and schedule challenges, the MNA display did not provide the driver with a map display that showed the names of the streets in the area. Technical challenges included letter size and placement of the street name as zoom levels changed. The map display screen did provide a graphical representation of the road network and indicated the road name of the street that the vehicle was on. As the vehicle approached a cross street, the name of the cross street was indicated. Drivers could zoom in and out while in the "map" mode, thus increasing the field of view or decreasing the display detail. The deficiencies associated with the display map however were not of great significance to the project as the turn by turn arrow display was considered the preferred display.

- MNA CD Drive

• The CD player selected for the *ADVANCE* project was chosen because it was specified to operate in an automotive environment. Standard audio CD players are not designed for data storage, nor will they meet the vibration, shock and temperature requirements of an automotive application. The CD player was specified to operate from -20 degrees C to plus 70 degrees C. During the summer testing of 1995, one of the hottest summers on record for the Chicago area, a significant percentage of the CD players were shutting down due to high operating temperatures. Using temperature recorders, it was determined that certain test vehicles' trunk temperatures exceeded 70 degrees C. To ensure that vehicle testing could continue, despite the extreme temperatures, a number of thermal management strategies were incorporated to reduce the in-trunk temperatures. These included combinations of the following during the field testing:

- Some vehicles had rear seats that folded down allowing cool air into the trunk.
- Vehicles were parked in shaded areas during lunch and coffee breaks
- Plastic CD player covers were removed to allow greater air flow.
- CD players were replaced in the field*

*Laboratory testing proved that some of the CD players did not meet the supplier's temperature specifications. These units were replaced with players that had been lab tested to 70 degrees C.

The *ADVANCE* Project field testing indicated that automotive environmental conditions were more extreme than anticipated. Improvement in this technology is required. It is our belief that CD player technology will continue to improve and new storage media developed as more navigation applications are offered in vehicles.

• CD Drive Speed-the unit used was a single speed drive as it was the only suitable drive on the market at the time the system design was done. It is speculated that a multispeed drive may shorten the access time appreciably for the user. Additionally, other technologies such as hard drives or smart cards may find use in this type of application.

• Robustness-to survive in an automobile environment, the equipment must be able to withstand severe shocks from vehicle operation. At the time of the system design, there were only a few manufacturers who could provide a CD drive which met automotive standards for shock. This in turn limited the ability of the designers with respect to drive speed, temperature range, etc. In the future, more options are expected to be available.

- MNA Location Systems

• Compass-while the main portion of the tests were conducted in the suburbs, it was found that when the vehicles were taken to downtown Chicago, major orientation problems with the compass occurred in initial tests due to the presence of steel in the high rise buildings, in parking garages and in the many bridges over the Chicago River. This ended up being only a minor irritant as positioning was based on three methods as noted below. As a result, the position typically remained accurate even with the loss of the compass.

• Global Position System-from the onset of the project, it was felt that GPS by itself, with a location accuracy of up to +/- 100m would be insufficient for navigational purposes. Thus, differential GPS with an accuracy of up to +/- 30m was used.

• Wheel Sensors-initially the MNA utilized wheel sensors to determine the distance traveled. It was found, however, that the sensors required frequent calibration as well as replacement due to wheels hitting curbs, rough spots on the road, etc. A more significant concern was the amount of time necessary to install the wheel sensors. Subsequently, transmission sensor(s) were utilized as replacements. This, however, restricted the vehicles in the project to those which had electronic pickups on the transmission (typically 1985 and later). It was not felt that this was an undue restraint as vehicles expected to participate in a full scale deployment would be that age or newer.

• Gyroscope-The wheel sensors also provided turn information through differential odometry and when they were removed, a gyroscope was added to provide rate-of -turn information.

Each MNA contained three positioning systems that worked in parallel: dead reckoning, map matching, and differentially corrected GPS. Except in very rare instances where a roadway was parallel to another (eg. with a four foot separation), these positioning systems performed well.

- MNA Navigational Computer

• Functionality-As the implemented functionality of the MNA increased and the map database size increased, it became apparent that hardware and software limitations of the navigational computer affected the speed of the user interface. Like all systems, faster is better and future similar systems will face similar challenges as the user wants more and wants it quicker.

- Reboot Button-Due to the tight schedule associated with Targeted Deployment, problems were identified in the software which could not be fully corrected in the time available. This necessitated the ability to easily reboot the navigational computer when these problems occurred. This was accomplished by the addition of reboot button on the dash which allowed for the navigational computer to be rebooted without stopping the vehicle and/or turning off the engine. This saved a significant amount of time during system testing and integration. A similar means of rebooting this equipment is proposed for future systems of this type to minimize downtime during testing and integration, and allow users a convenient re-start mechanism if problems occur.

- MNA Map Database

  - Database-The database provided was full and complete with respect to meeting the requirements for a navigable database. It contained street names, jurisdictional boundaries, one way streets, turn restrictions, etc. Several challenges needed to be overcome to use this database however:

    - To reduce the load on the RF communications subsystem, it was desirable to utilize the link ID's from the database instead of the full name of the street. It was initially thought the link ID's would be a constant which would aid in updating travel time profiles over time and during the evaluation efforts. It was found however that they were not all constant and that whenever new links were created, such as through the addition of forest preserve boundaries, two or more new link ID's were developed to replace the former link ID's To overcome this problem it was necessary to develop customized software in the TIC (eg. an alias table) to take historical travel times on a given link and to prorate them to the newly developed links.

    - The manner in which the map database was coded resulted in the creation of very short links, some of which were the length of a traffic island at an intersection. Other short links resulted from having separate directional links on divided roadways so that a short cross link between the two directional links was created. These short links resulted in two problems in MNA operation. The first occurred if you were following a route and the route involved a left turn across a roadway that had a median. In this instance, the MNA would give you a turn maneuver for a very short distance and time (eg. on the order of 50 to 100 feet) followed by a through movement which tended to be confusing to the drivers. This problem was overcome by verbally informing drivers of potential short link. The second resulted from the fact that the MNA updated its position every two seconds and if the link length was less than the distance traversed in two seconds, the travel time report for that particular link would be included in the previous or the next link. Consequently, a continuity check for links would fail. This short link problem was overcome by developing the short link resolver software in the TIC which prorated the travel times and temporarily turned off the continuity test for that particular link. This points out the need for developers of map databases for navigational purposes and the end users (eg. application developers) of these databases to maintain communications with one another to minimize implementation problems.

- Overall, the map database from NavTech was found to be accurate and provided a good base both for navigation purposes and for display purposes in the MNA and the TIC.

- MNA Testing

- Development Tools-The MNA had the capability, through a special port, to interface a laptop computer that could capture incoming and outgoing RF data streams. While this tool was intended for use by the system developers, it was also used by the system integrators. This significantly improved the ability to perform integration testing and trouble shooting. It is recommended that future projects specify external testing and development tools that can readily be used by both the developers and system integrators. These development tools should use higher level integrated application software that will allow technicians to debug the broader system.

- Proprietary Information-Due to the proprietary nature of the MNA, the integration team could not follow the data flow within the MNA and had to rely on monitoring the inputs and the outputs. This impacted the integration efforts as it was not always possible to determine what the output should be for a given input. Future testing of this sort should be done under conditions that allow the integrators to have access to select proprietary information, Nonetheless, it is expected that this will be an ongoing problem.

- TRF-Development of Static Profiles

- Static Profiles-It was originally proposed that the CATS transportation network model would be used to develop travel times on a link basis by time of day and day of week basis. Several challenges arose:

  - The CATS network model was not based on the same map database as that used in the vehicles. This necessitated the development of translation software for the conversion to be done electronically. Even then, it was necessary to manually enter travel time data for approximately 15% of the links. Hence, future systems of this type should strive to use very compatible databases or acknowledge that some translation, manual and/or electronic, will be required.

- Early discussion envisioned travel time profiles for 5 minute intervals for 24 hours per day for 7 days per week. This turned out to be overly optimistic-the traffic data was not available in the amount needed (eg. turning movement counts at signalized intersections were only available for peak hours in most cases); and the project schedule and budget needed to be met. Thus, travel time profiles were developed for M-TH (12am to 6am, 6am to 9am, 9am to 4pm, 4pm to 6pm, 6pm to 12am), Fri (12am to 6am, 6am to 9am, 9am to 4pm, 4pm to 6pm, 6pm to 12am), and on Sat/Sun. Under field testing, it was shown the profile intervals used were adequate for the intended purpose.

- Static Profile Update

- Static Profile Updates-static profile updates were to be developed on a regular basis to provide the route planner in the vehicles with the best possible historical travel times for route planning purposes. While the static profiles were updated frequently, it was not done without overcoming certain difficulties:

  - The procedure to update the static profiles involved running a program in the TIC. It took several hours to run and noticeably slowed down the operation of other processes on the TIC. Additionally, once the output was available, it needed to be manually reviewed and manual changes made prior to transmittal to Motorola for creation of new CD's for the MNA. The impacts were mitigated by running the program in the off peak hours when there was little demand on the system. A more automatic procedure should be provided in future systems that can utilize some form of automatic checking/comparison.

  - The original scheme called for the minimum travel times to be those at or below the speed limit in order to meet policy guidelines. This was found to give a false representation of the actual travel times on the roadways and subsequently this constraint was removed.

  - Static profiles were created from both RF transmissions and memory cards. Due to some concern, which turned out to be unjustified, about the robustness of the memory cards, they were read on approximately a weekly basis, at which time they would be only 2 to 10% full. This resulted in additional labor to process the cards and set up the data files. It also required maintenance of a larger number of files than if the memory cards were only read when they were full.

- TIC User Interface

Several challenges were encountered in the implementation of the user interface which resulted from an ongoing modification of the design. It should be noted however that ADVANCE was a prototype and was not intended to be a long term, fully operational/deployed system. The requisite functionality existed but lacked the sophistication and speed necessary for a fully operational 24 hour a day system. Challenges included the following:

- While the original intent was to design an easily used, quick interface with a great deal of system functionality, schedule constraints precluded full compliance with this goal. The result was that a great deal of time was spent on developing functionality leaving little time for the actual user interface. Hence, the initial interface was not fully user friendly and was fast in some operations and slow in others. The end result was that the user interface was evolving during the development and implementation as developers tried to improve the user interface and speed the operation. Future system development should allow for more time for user interface development in order to provide a very user friendly system and one that can be easily and quickly demonstrated to visitors.

- When the user interface was initially implemented, it was relatively slow. To improve the situation, it was necessary to increase the speed of the four processors from 50 MHZ to 72 MHZ and to make the software more efficient by reducing the amount of virtual memory paging. Future systems will have even larger databases to contend with and faster means will be needed to improve processing time and to improve the user interface. This may include the creation of multiple databases, filtering of the databases to remove extraneous information, use of faster processors or more processors, or use of more memory.

- The user interface operated on x-terminals due to equipment considerations. These terminals did not have any computing power and in essence, worked as dumb terminals. This increased the load on the Sun server with a resulting perceivable loss in performance. Future systems should maximize the use of “smart” terminals which could possibly run most if not all of the user interface software without affecting overall system performance.

- A window display showing the status of the various processes was provided to enable the operator to monitor the system. When this was initially implemented, the process status display showed only the status of the process, not if data was being received and processed. Future systems should include the status of the data received (eg. is valid data being received for processing?). This illustrates the importance of providing displays which are useful to the operator.

- An additional means for the operator to monitor the system was also developed. This involved displaying the last message received/sent for several major processes in the TIC. This was necessary due to the inability of the status lights to indicate if data was being received and processed versus the availability of the process itself only being monitored.

- A number of external data sources to *ADVANCE* required manual entry into the system after being received at the TIC. NWCD data was automatically transmitted to the TIC, but not directly into the project database. Road construction and maintenance information were faxed to the TIC. In these three instances, paper maps were frequently used to confirm the location prior to manually inputting the data into the database. This turned out to be very labor intensive. As a result, this process is being electronically automated for the C-TIC.

- SSI weather detectors provided a great deal of data. However, the raw data in itself was of limited use to the TIC operators. Following detailed discussions, a method of reducing the large amount of data to a limited number of messages (eg. making it more manageable) was designed. This illustrates that while raw data may be available, it is not useful until it is converted to a more manageable form. Due to schedule constraints, this was not implemented in the TIC but will be done in the C-TIC.

- Throughout the early project development, there were times when the TIC would fail and it would be difficult to identify the cause. As a result, a watchdog timer process was developed which dumped the system parameters to a disk file in the event of a system failure. This enabled the system developers to later analyze the fault. This illustrates the need to have a means available to developers to fully analyze faults that may occur. Since *ADVANCE* was not staffed 24 hours per day, this watchdog timer process was designed to also restart the system after a system failure, assuming the restart is possible. Implementation of this process minimized the system down time during development, testing and operational phases.

- Because of schedule constraints, the TIC interface was developed and installed with limited input from the users. User input was obtained in the development process through the Operations Sub-Committee, however changes were difficult because of schedule, conflicting priorities, or technical difficulties. Future systems should strive to develop a early prototype of the user interface and to obtain input from the users themselves.

- TIC Map Display

  • TIC Map Display-It was found to be difficult to provide street names on the map display. The TIC allowed for map zooming and problems were encountered with letter size, room to fit the street name and the need to avoid interfering with other names and streets as zoom levels changed. The problem was alleviated in the TIC by providing the operator with the ability to either type the street name and have the system locate the street on the map; or by clicking on a link on the map display and having the system display the street name in a window.

- Connections of the TIC to External Sources

  • Connections to External Sources-Data sources, other than probes, were connected to the TIC via telephone lines. In many instances they worked satisfactorily but in at least two cases, ongoing problems occurred due to noise on the telephone line. One case involved the connection to the onstreet masters for the closed loop traffic signal system. The other was the connection to the SSI computer at another IDOT facility. These lines were standard dial up lines. While the problems were normally quickly cleared by the telephone line, they did recur at infrequent intervals. Future systems may want to investigate the use of conditioned lines if these types of lines are compatible with the equipment involved.

- RF Communications

  • RF Communications-Initially the plan was to use a commercial off-the-shelf Motorola data radio product for the development releases of *ADVANCE* and then to switch to the ADVANCE high speed data radio for the deployment phase. With the decision to go to a Targeted Deployment, however, the lower speed data radio was kept through the Deployment Phase. While a proven product, it did create some challenges/design limitations including the following:

    • Besides having an antenna for the RF data radio and an antenna for the GPS receiver, each vehicle also had an antenna for the cellular phone. To minimize the chance of RF interference, it was necessary to separate the antennas as far as possible, preferably at least three feet. (This would have been necessary with any system involving an external antenna.)

    • As with most metropolitan areas, RF frequencies are in high demand. Obtaining the frequencies was very difficult and then it was necessary to have an efficient communications design to maximize the number of vehicles that could use a given channel. The Targeted Deployment design resulted in the ability to handle approximately 100 vehicles on a given channel pair. If the project had gone to full deployment, use of a higher speed data radio was planned with a capacity of over 2500 vehicles per channel.

- The RF modem used in *ADVANCE* had one limitation. It could not keep up with data streaming (broadcast) at the full channel capacity. Constant streaming data is not a requirement for the normal commercial application of a transaction based two-way radio modem. It was discovered that the modem was being taxed beyond its capabilities in this application. As a result, the outbound message rate was adjusted. (The change did not impact the conduct of the Targeted Deployment.)

- A second challenge also caused a further slowdown to the outbound messaging. The modem would receive messages every two seconds and pass them on to the MNA. This worked well as long as the MNA was not too busy. When the MNA was busy, the incoming messages would stack up in the modem buffer. Eventually the modem buffer would fill up and the modem would shut down. The solution was to slowdown the message rate. This action allowed the evaluation testing to be completed without problems.

- TRF Algorithms

Many of the challenges faced in implementing the TRF algorithms involved taking a theoretical development and applying it to the real world. While there is a separate paper on TRF algorithms, certain lessons learned are documented here.

- TRF Algorithms-The TRF algorithms were developed by University transportation engineers and coded into the TIC by University computer scientists. As with all areas where two diverse parties work together, this situation led to coordination and communication challenges. To ensure full communications between the parties, it was found to be very helpful to have regular meetings, often on a weekly basis, and to make extensive use of E-mail. The challenges encountered included:

  - Developer verification of code-It was found that having the TRF developers come into the TIC and physically check actual data output in order to verify proper coding of their algorithms was invaluable. It was also important to have both developers and coders in the TIC at the same time. As a result, when a problem was suspected, it could be identified and resolved in a timely manner. This process lessened the time required to find coding errors, previously left to the system integrators to find.

- Code flexibility-The TRF coders were reluctant to make changes to the TRF algorithm structures. This resulted in algorithm structures, particularly in Incident Detection, which were purposely designed larger/bulkier to allow for future algorithm "tweaking". As an extreme, the Incident Detection Algorithms contain equations which have components that are multiplied by a parameter initially set to zero. It was thought that if field testing suggested these components be utilized, the parameters could be reset to an actual value. Thus, while the algorithms could have applicability in a future system, they were more than that required for the Targeted Deployment and the design resulted in extraneous code being written for *ADVANCE*

- Communications amongst the TRF developers. The different components of TRF (DF, ID, SPU, TTP) were for the most part developed by different individuals, geographically separated at different Universities. As expected, communication between developers was critical to insure compatibility and maintain data integrity. This presented significant challenges throughout the development process. During the intense stages of Releases 1.5 and 2.0, TRF technical meetings were held regularly. These meetings were attended by all of the developers, as well as integrators and coders. This allowed significant problems and solutions to be identified and resolved in a timely manner. If one designer changed the method by which they calculated a variable, another designer's equation could become impacted. It was also important that everyone knew what units variables were in (eg. feet, miles, meters, etc.). Lastly, if one designer stopped using a particular variable, the designer who calculated that variable would have to be notified so that he could stop calculating the variable.

- As the scope of the Project changed, it was necessary to modify portions of the algorithms. Major modifications were made to the broadcast prioritization component of TTP, as well as to turning predictions from through maneuvers, due to the reduced number of probes. Changes were also made to SPU to account for the deletion of the weather component and deletion of special events. Modifications were also made to DF and ID. The challenge therefore was to stay abreast of the changes needed and to ensure that developers coordinated in making modifications to their algorithms. The aforementioned meetings, often on a weekly basis, were found to be extremely useful in keeping all parties aware of changes.

- It was found necessary for developers to specify parameters that could be changeable and not hard-coded. It was also important for developers (and system integrators) to work with the coders to develop the format of the data output files. This made it easier to validate code and monitor the algorithms. The challenge therefore was to keep the individual developers aware of the requirements of other developers. This was done through weekly meetings, E-mail and direct contact.

- When checking the consistency of detector data, it was found that a chart of occupancy versus travel time possesses two (2) distinct regimes of data points-a congested and an uncongested regime. It became necessary to check for consistency in both regimes.

- Road closures, lane closures and incidents do not have their effects decay at the same time after the event is over. This created some confusion when dealing with unique cases (such as a lane closure with and incident). Further research is needed to determine if the benefits of decaying each event uniquely is worth the effort involved.

- Heuristic tests were used (by TTP with the **TSC** TTP equation and by ID for probe and detector ID) when equations "broke down". It was found that at extreme conditions (eg. low occupancy/high volume) the accuracy of the equations was questionable. This was remedied by placing heuristic tests in the algorithms to check for the extreme cases.

- TRF Processing

- Onstreet Masters Data Transmission-The onstreet masters typically utilized volume and occupancy data on a 15 minute period. To be of use in this project, it was necessary to receive this data at the TIC in 5 minute intervals. This necessitated some changes in the software at the onstreet masters. In addition, the data transmission involved heavy use of telephone lines and the accompanying telephone charges. Future systems connected to onstreet masters will need to either accommodate these limitations in the same manner or design a more efficient/effective means of interface.

- Onstreet Masters Timing- Masters 1 and 92 on Dundee Road provided five minute and fifteen minute data that were transmitted via voice grade telephone lines and were not always received. Additionally, sometimes the call from a master would come in late or early and two (2) reports would be received in the same time period for the same detector. Algorithms in the TIC needed to be modified to account for this special case. This illustrates some of the results that occur when devices are used for purposes other than for what they were originally intended.

- Onstreet Masters Smoothing-Other challenges related to the use of smoothing factors. The TRF algorithms used smoothed volume and occupancy data. The five minute data was raw and the smoothing factors used in the onstreet masters needed to be used to convert the data.

While it was necessary to coordinate what factors were used onstreet with those used in the TIC, future use of similar data may want to allow for the option of raw or smoothed data.

In reviewing *ADVANCE,* one must take into consideration the state of the art and practice. The latest, most cost-effective technologies available were used. Many challenges were encountered that resulted from limitations in available technology. Others were caused by the schedule and budgeting for the project. All of these challenges were overcome and a successful, functioning in-vehicle navigation system was developed and deployed. The system had the ability to collect data from a variety of sources, to fuse data and to send updated link travel times to vehicles. The units in the vehicles had the ability to plan and display routes using static (historical) as well as dynamic travel times. Hence, the *ADVANCE* Project did reach its goal of demonstrating in real time, a functioning dynamic in-vehicle route guidance system.

4.0 SUMMARY

As a result of the technical challenges faced in the development of *ADVANCE*, several general recommendations can be made:

1. Close and frequent cooperation is required between all developers to ensure that all involved parties are aware of changes/operation of components being developed by others.

2. Close cooperation between the actual developers is as critical as that between managers.

3. Advances in technology will be required to meet the requirements of similar systems in the future. These advances relate to improving the speed of the user interface, transmitting high amounts of data quickly, improving how trips are planned, etc. Other advances relate to providing technology that can work in the wide range of environments encountered in automobiles.

4. Advances in location technology are required in order to fully meet the location accuracies required in future systems.

5. Installation of in-vehicle navigation units, with display heads next to the driver, will need to take into account air bag deployment. Attention will also need to be given to standardizing the installation of the system.

6. More research is needed with respect to items such as data fusion, incident detection and route planning algorithms.

7. The design of similar demonstrations should reflect what can be done with existing technology as opposed to over emphasizing the use of unproven technology.

8. The schedule for a project should reflect what is practical given a set budget, requirements and resources. These resources should consider technical complexity as well as available expertise, material and funding.

APPENDIX F

ESTIMATING ENVIRONMENTAL EFFECTS OF A PROBE VEHICLE-SUPPLEMENTED TRAFFIC INFORMATION SYSTEM WITH LESSONS LEARNED FROM THE *ADVANCE* TARGETED DEPLOYMENT

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ESTIMATING ENVIRONMENTAL EFFECTS OF A PROBE VEHICLE-SUPPLEMENTED TRAFFIC INFORMATION SYSTEM WITH LESSONS LEARNED FROM THE *ADVANCE* TARGETED DEPLOYMENT

EXECUTIVE SUMMARY

The *ADVANCE* targeted deployment was too limited in scope of coverage to permit useful conclusions to be drawn about either its specific environmental effects or what would have been the likely environmental impact of full deployment. Rather, this paper is intended to link some of the specific test experiences with the existing literature on ITS effects and thereby draw inferences about how driver behavior and response under an *ADVANCE* type of ATIS deployment would affect the vehicular emission results of such deployment and, by extension, of other ATIS concepts. The paper should be of interest to ATIS/ATMS planners and modelers, especially those in the pre-deployment phase of a fully-fledged system. It should be combined with companion documents arising from other ITS field operational tests as one of a set of qualitative "informal guidance" documents. However, its applicability is probably limited to deployments at a scale no greater than that of *ADVANCE* itself.

Findings are as follows:

1) Results of tests involving drivers familiar with the *ADVANCE* network suggest that drivers with good network knowledge and no constraints on the use of local streets often believed they could find faster routes than those offered by the *ADVANCE* system; this in turn suggests that it may be possible to generate more net time savings if route planning constraints are relaxed and the number of candidate routing links thus increased.

2) It appears that no driver would completely relinquish navigational control to a real-time ATIS navigation capability so long as known limitations or impairments of network data remain in the navigation data base. Policy considerations at the present time preclude the removal of all such limitations, and this minimizes the extent to which any emission benefit of this ATIS concept can be measured or attributed.

3) Nothing revealed by the *ADVANCE* field tests refutes the conclusion appearing in ATIS research literature that, during periods of recurring congestion, those who experience the highest costs from congestion will have found ways to alter their routes or timing, and those who are more willing to bear congestion costs will stay on congested roads. The *ADVANCE* user population could not be reliably separated into these two groups, so no inference can be

offered about the likely broader driver population split between congestion rejecters and congestion acceptors.

4) Reliable real-time information during periods of *nonrecurring* congestion, the provision of which is a key component of *ADVANCE* and similar ATIS deployments, appears to possess a high implicit value for virtually all drivers.

5) It follows that, in order to maximize the probability that real congestion reduction and emissions improvement will result from an ATIS deployment, the system should have the following features:
   a) accurate information on link traffic conditions available with the shortest possible delay in communicating it to ATIS users;
   b) an accurate, reliable route planner with few if any limitations on link/route combinations; and
   c) a convincing argument to the would-be purchaser of ATIS services that real, measurable benefits *will* accrue to him/her.

   The *road network* in which this system is to operate should have alternative route options that are faster and not too much longer (significantly greater length can mean higher emissions) than the original route of choice, and which generally have excess capacity (mitigating the problem of diverted congestion).

6) Another way of stating point 5(c) is that the gap between system *potential* and actual system *performance* must be closed before the confidence of prospective ATIS users can be won sufficiently to make them acquire the system and act consistently on ATIS guidance.

ESTIMATING ENVIRONMENTAL EFFECTS OF A PROBE VEHICLE-SUPPLEMENTED TRAFFIC INFORMATION SYSTEM WITH LESSONS LEARNED FROM THE *ADVANCE* TARGETED DEPLOYMENT

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1.0 INTRODUCTION

The Advanced Driver and Vehicle Advisory Navigation ConcEpt (*ADVANCE*) advanced traveler information system (ATIS) demonstration project in northeastern Illinois was re-scoped in late 1994 from its originally-planned deployment of 3,000 - 5,000 in-vehicle navigation units to a "targeted" deployment in which up to 75 vehicles were equipped with devices enabling them to receive real-time traffic information. These devices included a navigation system that employed. a comprehensive map data base and average (static) link travel times by time of day, stored on CD-ROM, which together computed efficient (approximate least duration) routes between any origin and destination in the northwest portion of the Chicago metropolitan area. The dynamic component of each device was a global positioning satellite (GPS) receiver coupled with radio transmission capability that enabled the vehicles while in the ADVANCE study area to serve as dynamic traffic probes as well as recipients of travel time and location data. Experiments were designed to dispatch these equipped vehicles along links at headways or frequencies comparable to what would have been observed had full deployment actually occurred. Thus, within the limitations of this controlled environment, valuative experiments were conducted to assess the quality of several of the key sub-systems of *ADVANCE* in the context of structured performance hypotheses. There was particular interest in the ability of equipped vehicles to (1) both generate and receive time-saving reroutes in congested corridors, (2) transmit (together with fixed detectors and anecdotal police and motorist reports) to a Traffic Information Center (TIC) timely and accurate information about road conditions and incident-related congestion that in turn would generate reliable link and route travel time estimates useful in real time, and (3) provide an informational package and structure having both appeal and utility for drivers generally familiar with routes and traffic conditions in the study area.

The targeted deployment was limited in scope of coverage and restricted the ability to develop useful conclusions about either its specific environmental effects or what would have been the likely environmental impact of full deployment. Rather, this paper is intended to link some of the specific test experiences with the existing literature on ITS effects and thereby draw inferences about how driver behavior under an *ADVANCE* type of ATIS deployment, operating in an environment summarized by the three elements described in the final sentence of the preceding paragraph, is likely to affect the vehicular emission results of such deployment and, by extension, of other ATIS concepts. Because the future availability of navigational aids and real-time traffic information (i.e., ATIS without advanced traffic management) is far more likely to be determined by private vendor/developer initiative and investment than by major public works projects, the *direct* benefits of these ATIS concepts may be limited to the individual motorists who purchase such services. In fact, as shown in Figure 1, estimation of the overall distribution of benefits and disbenefits among users and non-users is a multi-layered and complex process. This paper will devote some attention to the issue of whether the direct benefits to such a comparative minority of motorists, those equipped with real-time ATIS capability such as dynamic route guidance, can in any consistent way generate environmental benefits for everyone in the airshed, motorists and non-motorists alike.

1.1 Acronyms and Definitions

All terms and acronyms used in this document that are specific to the *ADVANCE* project and thus potentially unfamiliar to the reader are defined in the System Definition Document #8020.ADV.06, available for examination and downloading on the Internet at the following URL:

http://ais.its-program.anl.gov/

Other acronyms are spelled out in the report on first use.

1.2 Authors

Contributing authors to this document are:

(1) Christopher L. Saricks, *ADVANCE* Evaluation Manager, Center for Transportation Research, Argonne National Laboratory (ANL). ANL was contracted to manage the evaluation of the *ADVANCE* targeted deployment in April, 1995, with Mr. Saricks designated chief project liaison and ANL site manager. Mr. Saricks has been with ANL since 1979, and has over 20 years' domestic and international experience and more than 50 publications in urban transportation analysis, forecasting and planning for Federal and State Governments and in private consulting. Among his previous positions was that of Director of Environmental Analysis for the Chicago Area Transportation Study. His graduate degree is from the London School of Economics and Political Science.

(2) Siim Soot Associate Professor of Urban Planning and Acting Associate Director, Urban Transportation Center, University of Illinois-Chicago (UIC-UTC). UIC-UTC has been actively involved in the *ADVANCE* project since its inception, and was responsible for the conduct of all field evaluation tests relating to the travel time prediction algorithms of the traffic-related functions (TRF) subsystem of *ADVANCE*. Dr. Soot directed these tests. A member of the UIC faculty since 1970, he has worked on numerous research projects funded by federal, state and local agencies, most dealing with the relationship between land use and transportation systems and how travel behavior is affected by these systems. Extensive data collection activities, including the distribution of one million survey instruments to Chicago transit users and the survey of several thousand Chicago downtown travelers, have been integral to these projects. He has published several dozen articles in academic journals.

(3) Joseph L. Schofer Professor of Civil Engineering and Transportation, McCormick School of Engineering, Northwestern University. Dr. Schofer has been affiliated with the Northwestern University Transportation Center (NUTC) for over 25 years and has published nearly 100 papers and journal articles in the field of transportation. NUTC was a partner in the development of the original ADVANCE deployment concept, as a member of the Illinois Universities Transportation Research Consortium, and was responsible for conducting the evaluations of the dynamic route guidance and incident detection capabilities of the Targeted Deployment, as well as the analysis of the response of familiar drivers (residents of the test area) to the *ADVANCE* navigation and real-time route guidance features.

(4) Joseph Ligas Director of the *ADVANCE* Project and ITS Program Manager for the Illinois Department of Transportation, is a Registered Professional Engineer with over 30 years' experience in transportation project planning and implementation in Illinois. Prior to his present position, Mr. Ligas was Deputy Director for Operations Planning at the Chicago Area Transportation Study, where his responsibilities included private sector liaison, traffic engineering assistance, and coordination of Operation Green Light (a congestion management program for northeastern Illinois). He received his Bachelor of Science degree from the University of Detroit and completed graduate study at the University of Illinois.

1.3 Intended Audience

This paper should be of interest to ATIS/ATMS planners and modelers, especially those in the pre-deployment phase of a fully-fledged system. It should be combined with companion documents arising from other ITS field operational tests as one of a set of qualitative "informal guidance" documents. However, its applicability is probably limited to deployments at a scale no greater than that of ADVANCE itself

1.4 References

The interested reader is invited to consult the evaluation test plans for the ten focused field tests of the targeted deployment if more detail than that provided below in Sec. 3.2 is desired. These plans are resident at the Internet at the URL shown above, with the following document control numbers.

8460-l.ADV.0l	Base Data and Static Profile Evaluation Test Plan (revised)
8460-2.ADV.0 1	Data Screening Evaluation Test Plan (revised)
8460-3.ADV.0 1	Quality of Probe Reports Evaluation Test Plan (revised)
8460-4.ADV.0 1	Travel Time Procedures and Performance of Probe and Detector Data Evaluation Test Plan (revised)

8460-5.ADV.01	Detector Travel Time Conversion and Fusion of Probe and Detector Data Evaluation Test Plan (revised)
8460-6.ADV.01	Frequency of Probe Reports Evaluation Test Plan (revised)
8460-7.ADV.01	Relationships among Travel Times Evaluation Test Plan (revised)
8461 .ADV.0l	Incident Detection Evaluation Test Plan (as revised)
8462.ADV.00	Familiar Driver Evaluation Test Plan
8463.ADV.00	Dynamic Route Guidance - Yoked Driver Study Evaluation Test Plan

All other cited works are listed in footnotes on first appearance in the paper.

1.5 Report Organization

An introduction is provided in Section 1. Section 2 discusses the purpose of the paper, while Section 3 presents findings, including subsections that cover field test methodology, relationship to existing literature on environmental effects of ITS, and discussions of data collected and inferences drawn. Section 4 provides the report summary and a compendium of the lessons learned.

2.0 PURPOSE

Although deployment of the *ADVANCE* dynamic route guidance system was scaled back significantly from its originally-intended scope, observed and recorded behaviors of the drivers who utilized this system gave rise to inferences about the potential vehicular emission benefits--or lack thereof--of such a system. This paper will discuss those behaviors and inferences, and attempt to draw conclusions based on the limited driver use and trends exhibited.

3.0 METHODOLOGY AND FINDINGS

3.1 Background

The original planning for the *ADVANCE* deployment called for compilation throughout the expected two-year project lifetime of a large evaluation database that would have provided the basis for broadly informative and reliable tests of the various features of the project's systems and subsystems with respect to their capability to perform their stipulated missions. With the re-sizing of the project to a smaller, targeted deployment, plans for assembling an evaluation database changed in scope: although sample sizes and the number of data points were significantly diminished, it should still be possible to collect data adequate to inform other field operational tests about expected performance of and user response to similar system deployments. This philosophy resulted in the evaluators devoting considerable attention to defining the objectives and resources necessary to conduct useful tests, then to deriving a feasible schedule under known time constraints for conducting them. The evaluation test plans ultimately prepared for the field activities identified, as applicable,

1) the data to be collected and the procedure for its collection,
2) the hypotheses about system performance to be tested using these data,
3) the chronological window(s) (calendar dates) during which data would be collected, and
4) the number of vehicles, hours and drivers required daily to perform the test procedure.

Note that there was no explicit environmental impact component to the data collection plan, despite there being considerable interest in the transportation and environmental planning communities in the potential air quality and energy productivity effects of ITS deployments. In fact, the draft action plan for the Energy and Environment Committee of ITS America embraces the "...generally shared principle...that ITS technologies have environmentally friendly applications and that it is in the public interest to take advantage of them...[the Committee] will work to assemble a database of existing documentation on environmental impacts of ITS deployment that has taken place thus far." [1] This database is still extremely sparse due to the paucity of deployments of sufficiently large scale, and most conclusions in literature to date are based on the results of simulation exercises that apply widely varying methodologies and levels of sophistication. [2] The *ADVANCE* targeted deployment

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[1]Action Plan For the Energy and Environment Committee (EE)," ITS America, l/9/96.

[2]Recent examples are discussed or presented in (a) S.H. Cadle, B.K. Bailey, T.C. Belian, M. Carlock, R.A. Gorse, H. Haskew, K.T. Knapp, and D.R. Lawson, "Real World Vehicle Emissions: a Summary of the Fifth Coordinating Research Council On-Road Vehicle Emissions

provided no quantifiable measures to expand the database, and its test designs permitted only conjectural judgments to be offered about whether results from the literature point in the right direction. Thus, despite the meticulous data collection effort for the targeted deployment, the present report is both entirely qualitative and highly restrained in its findings.

3.2 Methodology

Field testing was conducted as described below in support of performance evaluation for each of three major *ADVANCE* system features.

1) *Traffic-Related Functions: the travel time prediction algorithms used by ADVANCE to provide route guidance in real time.*

Purpose: to evaluate the performance of the components of the Traffic-Related Functions (TRF) Subsystem and the relative usefulness of probe-equipped vehicles vs. the in-pavement loop detectors in providing real-time traffic data.

Procedure: the seven inter-related TRF field tests, managed by University of Illinois at Chicago Urban Transportation Center (UIC-UTC) faculty, used paid drivers operating up to *15 ADVANCE* system-equipped vehicles four days per week (Monday-Thursday). The vehicles were driven along predetermined routes for which their traversal times for each link were recorded at the Traffic Information center (TIC) along with arterial loop detector data. These were analyzed to determine the performance of key TRF components. These components included: fusion of data received from probes and detectors into a travel time prediction algorithm; construction of both the default static forecasts and the on-line dynamic forecasts; estimation of the number and frequency of probe traversals required for reliable travel time updates; and the relationship among vehicles' travel times on a link as a function of turning movement and directionality.

Workshop," *J. Air & Waste Mgmt. Assn.* 46 (April 1996), 355-369; (b) B.J. Kanninen, "Intelligent Transportation Systems: an Economic and Environmental Policy Assessment," *Transp. Research* 30A:l (January 1996), l-10; (c) J.E. Hicks, D.E. Boyce, and A. Sen, *Static Network Equilibrium Models and Analyses for the Design of Dynamic Route Guidance Systems*, Illinois Universities Transportation Research Consortium for Illinois Department of Transportation, October, 1992; and (d) R. Arnott, A. de Palma and R. Lindsey, "Does Providing Information to Drivers Reduce Traffic Congestion? *Transp. Research* 25A:5 (September 1991), 309-318.

2) *Dynamic Route Guidance: the provision of routing and re-routing information directly to a driver based on current conditions.*

Purpose: to determine whether, and to what extent, dynamic route guidance (DRG), as implemented in the *ADVANCE* system, can provide improvements in drivers' travel times.

Procedure: this test had two central facets--yoked-driver (YD) timing and incident detection (ID) timeliness. In the yoked driver (DRG/YD) tests, triads of equipped vehicles operated by paid drivers were driven at approximately identical start times between a preselected origin and destination. Two members of each triad followed routes planned and updated in real time through the communications link with the TIC, while the other followed a fixed (or static) route defined by the in-vehicle navigation unit using only its embedded map and travel time data (i.e., no TIC communications). Two dynamically-guided vehicles were used because of the high risk and high cost (to the test) of probe-reporting failures. Up to 18 equipped vehicles acting as probes departed ahead of the pair along alternative routes between each planned origin and destination to provide frequent travel time updates to the TIC. The objective was to determine whether and how frequently the members of the pair that had full communication were given a route different from that provided by static guidance only *and* which saved time relative to the static route, or at least received a different routing to indicate the potential for time-saving benefit in other, similar circumstances. These tests were managed by faculty of Northwestern University Transportation Center (NUTC) and conducted by drivers hired by the university.

Dynamic route guidance also requires reliable and accurate real-time information to be provided about the expected delays (relative to static average travel times) caused by traffic accidents/incidents and construction activities on traffic links along a route. As part of the incident detection (ID) evaluation, pre-staged and roving field vehicles from a deployed fleet of up to 12 were dispatched in real time to the scene of either a reported incident or known actual (or simulated) construction delay. If an actual delay condition was found, these probe-equipped vehicles traversed the affected area repeatedly to measure travel times. Later, the vehicles returned to the incident sites to record travel time during normal conditions. The reliability of the algorithm that identifies construction and incident delays by means of loop detector data and data fusion was also evaluated with data collected from these traversals. Tests were conducted by NUTC during weekday periods of both recurrent and non-recurrent and incident-related congestion, and both naturally-occurring incidents and staged incidents were used.

3) *Familiar Drivers: value of dynamic route guidance to drivers who know the road network.*

Purpose: to provide drivers familiar with the *ADVANCE* test area with an opportunity to use the *ADVANCE* system in their normal driving behavior for a relatively extended period of time. Based on this experience, it was expected that these drivers could provide a useful perspective on the characteristics and performance of the *ADVANCE* system, and from this could offer guidance for the design and development of future Advance Traffic Information System (ATIS) services.

Procedure: this series of tests made use of 80 families living in the test area that had volunteered to drive *ADVANCE*-equipped, project-supplied vehicles for a two-week period, and who were willing to fill out both baseline and post-test surveys and to maintain drivers' logs noting malfunctions, problems, reroutes and responses thereto. Subsequently, 30 percent of the drivers participated in focus groups that examined their respective experiences and reactions. This test and follow-on focus groups were managed by Northwestern University.

Two of the targeted deployment field tests (DRG/YD and Familiar Drivers--FD) specifically focused respectively on travel time savings and driver responses to real-time trip routing. In a third set of tests (TRF), the precision of the algorithms that generated dynamic travel-time information in *ADVANCE* was investigated, so these tests had indirect bearing on the quality and usefulness of information provided to travelers for the purpose of reducing trip times. Our discussion deals primarily with the DRG/YD and FD tests, but also touches on the use and reliability of vehicle probe data as evaluated by the TRF tests as a primary source of real-time route guidance.

3.3 Key Assumptions and Constraints

Vehicular and personnel resource limitations circumscribed each *ADVANCE* field tests within the very limited breadth of focus on their specific mission.[3] Thus, any conclusions that have an environmental flavor--for example, identification of a relationship between a) driver behavior as modified by real-time information about travel times and b) traffic flow efficiency in the subnetwork where the information was available--are purely conjectural for any test. In fact, the boldest

[3]For example, even had the recommended environmental evaluation framework of the Volpe National Transportation Systems Center's ITS study group (Goodman, T., X.P. Huang, J. Mergel, and C. Little, "Evaluation Structure for Emissions and Fuel Consumption Impacts of ITS Deployments," Paper no. 32, 1996 Annual Meeting of ITS AMERICA, Houston, TX [April 15-18, 1996]) been available to the *ADVANCE* evaluation team prior to conduct of the various field tests, nothing consistent with that framework could have been structured to enable a reliable statistical test of the environmental impact of the targeted deployment to be performed.

assumptions of this paper are that environmental effects findings to date in the ITS literature have legitimacy sufficient to permit their application to the *ADVANCE* experience, and that this experience in turn has legitimacy sufficient to supplement existing literature.

3.4 Trip Time Savings and Driver Response

3.4.1 Dynamic Route Guidance

The dynamic route guidance/yoked driver tests were designed to (a) maximize the amount of short-term information about link traversal times available to drivers equipped with *ADVANCE* real-time navigation units between an origin and a selected destination about 15 to 20 minutes distant and (b) to compare the travel times between these O/D pairs for vehicles receiving this real-time information (i.e., routes determined by the very recent link traversal data) and those with access only to the "average" link traversal times available from the on-board CD-ROM road network database (no travel time updates available in real time from the Traffic Information Center--TIC).

To accomplish (a), probe vehicles transmitted their link traversal time by radio frequency to the TIC, which then passed these data through the *ADVANCE* link travel-time estimation algorithms, a process that filtered the inputs and generated travel-time messages for dynamically-guided vehicles. Shortest travel times for given O/D pairs were computed based on probe vehicle "flooding" of all reasonable route configurations on principal arterial roads connecting an O/D pair over an approximately 15-minute period. Preliminary results from an analysis of the frequency of probe traversals per unit time required for reliable real-time travel estimates had earlier indicated that at least three traversals in a 15-minute period were required. Thus, probe-equipped vehicles were dispatched along 5 or 6 different routes connecting an O/D pair at approximately 5-minute intervals until at least three vehicles had been dispatched to travel each arterial link; this assured that each link option traversed received the needed coverage. Then, (b) was accomplished according to the procedural description in Sec. 3.2 above, with both departure and arrival time recorded for all "yoked" vehicles. If the dynamically-informed vehicle consistently arrived first, there would be convincing evidence that this type of ATIS did save travel time for its user and thus decreased the total exhaust emissions and energy consumption *enroute* relative to the same trip without such guidance. Whether or not this occurred, if static and dynamic routes were at least different, evidence was weaker but still indicative that real-time data *could* provide a benefit to drivers.

The *ADVANCE* study area road system is predominantly a grid of primary and secondary arterials and residential streets, with a few multi-lane limited-access facilities transecting the area north to south and east to west. Thus, point-to-point trips *within* the study area follow routes offering few options for using segments on which access is fully controlled. Additionally, by policy decision early in the project, routing options offered by the *ADVANCE* navigation system deliberately excluded local roads that might route "bypass" traffic through residential areas. Both of these factors weighed heavily in assessing whether dynamic route guidance could really reduce total travel time within the study area.

To some degree, results of the DRG tests were limited if not actually confounded by the *ADVANCE* route planning algorithm. That is, whether a travel time benefit was produced depended in part on the character and quality of this algorithm, which included restrictions built in by prior agreement. The algorithm itself is proprietary to the developer of the *ADVANCE* in-vehicle unit, so it was not possible to evaluate it directly and formally. It would have been desirable to compare results of the *ADVANCE* route planning algorithm with one or more published algorithms as benchmarks, but it was decided, in order to conserve evaluation resources, not to do this because future ATIS developments would be employing different algorithms, possibly more open to review.

Some 79 O/D pairs were run during the 5-week period of the yoked driver tests. There was little evidence of time savings between dynamic and average-travel-time routings across the board, although one or two of the pairs did experience a few dynamically-determined routes (especially during peak traffic hours) that saved several minutes' time. Most of these time-saving routes could take advantage of just-received information about construction slowdowns on component links of the average "best" route. Indeed, the dynamic and average routes presented were often different whether or not significant time savings were available (suggesting that the travel time prediction algorithms at the TIC were functional, if somewhat optimistic), but the options presented were constrained by use of the arterial and collector (but not local) steet network, the route planning algorithm, and the rapidly-changing nature of local traffic conditions. Thus, the best available diversion might route a vehicle around an incident or construction slowdown by diverting it to a parallel arterial a half mile away; by the time the vehicle rejoined the original route, the cause of the slowdown might have been mitigated significantly to restore normal to near-normal traffic flow to the affected link. Public safety agencies within the study area have a remarkably impressive record of prompt dispatch to the scene and clearance of obstructions due to on-road incidents. As a consequence, there were few instances during the tests in which *unplanned* delay resulted in a link tie-up of duration sufficient to keep routings that avoided that link (but would otherwise have used it) preferable for more than a few minutes--about the time required to get to the parallel arterial and back. In a denser, heterogeneous and generally more congested road network (for example, offset grids overlaying radials, circumferentials and skewed diagonals), more flexible and productive rerouting might have been identified. On the other hand, a high level of congestion due to rerouting might have resulted in fewer opportunities to save time.

Results of the familiar driver tests (see below) suggest that drivers with good network knowledge and no constraints on the use of local streets believe they could find faster routes than those offered by the *ADVANCE* system, which in turn suggests that it may be possible to generate more net time savings if route planning constraints are relaxed and the number of candidate routing links thus increased. (The opening of local streets as candidates poses a dilemma for municipalities in which so-called "by-pass" traffic already seeks out residential streets to avoid congested links. In the real world, safety and citizen concerns must be placed on an equal footing with potential travel time savings across the network.)

3.4.2 Familiar Driver Response

Eighty pre-screened households in the study area with at least one registered driver (most had two) participated in a test in which the household drove an *ADVANCE*-equipped vehicle provided by the project office for an unbroken two-week period. Each vehicle was garaged at the participant's home and treated as one of the family cars. Participating households represented a reasonable demographic and economic cross-section of the study area, which is more economically homogeneous than the Chicago metro region in entirety. Although drivers were permitted to drive the vehicles outside the study area (including operation in any county adjacent to those covered by the *ADVANCE* data base), the primary purpose of their "in-home trial" was to evaluate whether an individual having more or less expert knowledge of a road network could benefit from an in-vehicle navigation aid providing up-to-the-minute route guidance on their trips within that network. Thus, while most navigation units now on the market stress their advantages to the unfamiliar or "lost" driver, little is known about the untapped and potentially much greater opportunity to produce travel benefits for a market comprising familiar drivers.

Two instruments collected data from participating drivers about their reactions to the two-week experience: an exit survey, and one of three focus group sessions. A consistent theme in the responses collected from these instruments was mild dissatisfaction about the limitations and occasional inaccuracy of the routings offered by the *ADVANCE* navigation unit. The combined effects of the absence of presumably more direct or faster routings involving local streets, and of the logic of the routing algorithm itself that tended to direct trips to the highest level facilities as soon as possible, eliminated from consideration some of the links *known* by the drivers to be on superior routes. In addition,.several local links were discovered by familiar drivers to be incorrectly coded in the map database (e.g., shown as through streets when they were in fact discontinuous, or as including intersection turning options not permitted in the actual network). Driver reaction to what appeared to be irrational routings ranged from total disregard of the navigation assistant (the driver's known "better" route was taken) to scrupulously following its directions and subsequently expressing dissatisfaction with *ADVANCE* routes. In a small number of cases, the *ADVANCE* route proved to be an actual time saver not previously known to the driver. For those drivers who experienced such a routing, respect for the *ADVANCE* unit's capabilities increased.

While the *ADVANCE* familiar drivers entered their two-week experience with generally positive expectations for system performance, it did not take long for them to appreciate the system's routing limitations. Nevertheless, it appears that an immersion experience like the familiar driver tests has the potential to mitigate *apriori* biases that a driver who believes he or she adequately knows a road network may hold against an automated system able to utilize real-time travel time information generated by other probe vehicles. As established by the TRF tests of probe travel time data quality *vis-a-vis* that of base network flow model as updated (or not) by static profile average time estimates, a large number of probe vehicles traversing an area at any given time--even as few as three on a link per 15-minute interval--will generate reasonable information about traffic flow in the network, potentially identifying any routes which offer real time savings. There are indications that the more this happens in real driver experience, the more the driver will come to trust the navigation unit. However, it appears that no driver would completely relinquish directional control to the unit. Policy and safety considerations preclude the removal of many limitations, minimizing the extent to which any emission benefit of this ATIS concept can be measured or attributed.

3.5 Connections with Previous Findings

Although preliminary results of limited ITS deployments are reported,[4] there has been little discussion of environmental effects of ATIS deployments outside the context of ITS operations in which a greater degree of top down management and control is present. For example, automated highway systems (AHS) have received a great deal of attention in the congestion mitigation/speed smoothing (energy conservation) arena. ATIS systems like *ADVANCE* do not exemplify the direct flow control of AHS, yet drivers' ability to access current travel-time information and thus avoid less desirable conditions could reduce, albeit more modestly than AHS flow management, the carbon monoxide and reactive hydrocarbon emissions associated with stop-and-go and low-speed (< 15 mph) congested driving and with the combustion enrichment of high acceleration transients [Cadle *et al.*, footnote 2(a)]. Results of stochastic modeling of traffic flow in a hypothetical network in which varying levels of route guidance availability to drivers and of trip route dispersion may exist (a system rather like the *ADVANCE* network, i.e., not dominated by flow along a principal corridor facility) suggest that both guided and unguided drivers enjoy benefits--those of the latter more

[4] D. Shank and D. Roberts, "Assessment of ITS Benefits--Results from the Field," Paper no. 139, 1996 Annual Meeting of ITS America, Houston, TX (April 15-l 8, 1996). With respect to the ATIS application in Boston (SmarTraveler), this paper reports that drivers diverting from congested freeways due to variable message sign information reduced their trip CO emissions by 33%, HC emissions by 25%, and NOx emissions by 1.5%. Diverting drivers represent between 5 and 30 percent of total flow; however, emission reduction estimates are based on traffic flow simulation rather than actual determination of specific trip ends of the diverting drivers. These diversions were not modeled to be sufficient in number to cause congestion on alternative routes.

modest than of the former--in terms of reduced average travel times and increased space mean speeds, a change in conditions likely to reduce emissions in a predominantly arterial regime. Such benefits increase as the proportion of vehicles guided and/or the dispersion of routes in the system increases, but the rate of increase is more dramatic when system-optimizing rather than *user*-optimizing information is provided [Hicks, Boyce, and Sen, chapter 6--cited in footnote 2(c)].

ADVANCE, of course, is a system designed to maximize route guidance benefits for the individual user, consistent with presumptions in most literature that direct benefits will accrue only to the relatively small subset of drivers who invest in or subscribe to them. However, most literature focuses on congested travel (i.e., freeway/expressway) corridors rather than arterial grids. In this context, some analyses show that direct benefits are maximized when the total number of subscribers *remains* small, and diminish substantially as a higher proportion of vehicles in the traffic flow has access to the same real-time information [Arnott *et* al., footnote 2(d)].

While expected (per-driver) travel costs are lower when full information is available to drivers with in-vehicle systems, this perfect information case will be difficult or impossible to attain, as the *ADVANCE* experience suggests. If only imperfect or incomplete information is available, drivers may be worse off than without information. For example, equipped drivers may receive information sufficient to divert from a problem route, and this may mitigate congestion for the remaining, presumably unequipped, drivers on the route abandoned, However, without full and timely information about conditions developing elsewhere, equipped drivers may increase the volume on alternative routes whose capacity is already overused and thus produce additional congestion that would not exist in the absence of route guidance. Hicks, Boyce, and Sen, in Chapter 6 of their work, identify this potential in a regime where routes are minimally dispersed, such as a freeway corridor. In their model, at least one instance of the equilibrium, equal travel time case for guided travelers following *user-optimal* routes places them on congested links.

Acceptance by ATIS-equipped drivers of guidance updates is a cornerstone of the success of any system, but such acceptance cannot be taken for granted. As Kanninen [footnote 2(b)] says:

> "...during periods of recurring congestion, people (with access to ATIS) will have already optimized their trip routes and timing to deal with congestion. In other words, people will have already sorted themselves out so that those who experience the highest costs from congestion have found ways to alter their routes or timing and those who are more willing to bear the congestion costs stay on the congested roads during these times. Adding new information to this long-run equilibrium *[sic]* might not alter the amount of congestion that exists."

Nothing revealed by the *ADVANCE* field tests can refute such conclusions, yet the limitations of the deployment precluded attempting a valid test of their merits. *ADVANCE* tests do indicate that instances of major benefit will occasionally accrue to users due to detection and avoidance of *non-recurrent* congestion. However, Kanninen's point is that *acceptance* of congestion or (presumed) transitory delay may be preferable to diversion onto less-travelled streets for drivers lacking confidence or a sense of security in the alternative routes offered by ATIS. For drivers who do divert, there may also be a limit to the acceptability of circuity in a revised route. The outcome for them could be selection of the "best case" parallel alternate, which congests with diverting vehicles (perhaps more quickly than ATIS' real-time rerouting feature can respond) and itself becomes an emissions "hotspot" not previously charted. With both the primary route and primary alternate subject to stop-and-go driving, total travel time may increase. Thus, net CO or HC benefit may be indeterminate or negligible.

The key to interpreting this case is to understand that an ATIS of the *ADVANCE* type cannot *guarantee* flow improvements or emissions reduction, but should at minimum possess the following features for the best chance at success in these objectives:

1) accurate information on link traffic conditions available with the shortest possible delay in communicating it to ATIS users;

2) an accurate, reliable route planner with few limitations on link/route combinations;

3) a convincing argument to the would-be purchaser of ATIS services that real, measurable benefits *will* accrue to him/her;

4) alternative route options that are faster and not too much longer (significantly greater length can mean higher emissions) than the original route of choice, and which generally have excess capacity (thus mitigating the problem of diverted congestion).

The first two features require careful attention to system architecture--that is, the technology for accomplishing them must be built into the hardware and software well before the system is actually deployed--while the third implies the creation of a strong positive message for communicating about, and frequent performance monitoring and quality checking of, the system in operation, The fourth feature says that there must be unused system resources (i.e., network capacity) to achieve a perceptible service improvement; ATIS can identify excess capacity, but not create it.

The TRF tests for *ADVANCE* have established that a relatively small population of ATIS-equipped vehicles *that identify their ownposition* can produce travel time data of high quality and reliability that can in turn be made available to a broader population of vehicles. It would then be up to this larger population of ATIS users who may or may not be probe-equipped to adjust their travel patterns based upon the information provided if measurable net improvement in emissions is to be realized. *ADVANCE* has revealed that the gap between system *potential* and actual system *performance* must be closed before the confidence of such users about the usefulness of ATIS information can be won sufficiently to make them act, without significant exception, on that information.

4.0 SUMMARY OF LESSONS LEARNED

The *ADVANCE* targeted deployment, because of its very limited scale and focus, did not involve any systematic testing or evaluation of the environmental effects of a probe- and detector-based ATIS. However, some insights were gained during the tests, especially those involving dynamic route guidance and familiar drivers, into *the potential* for such a system and what would be needed in that system to provide the best hope for actual environmental benefit after deployment. These insights are briefly recapitulated below.

1) Nothing revealed by the *ADVANCE* field tests refutes the previous conclusion that, during periods of recurring congestion, those who experience the highest costs from congestion have found ways to alter their routes or timing and those who are more willing to bear congestion costs stay on congested roads. However, .

2) This very conclusion argues cogently for the high value and usefulness of reliable real-time information during periods of *nonrecurring* congestion, the provision of which is a key component of *ADVANCE* and similar ATIS deployments. Therefore,

3) To maximize the probability that real congestion reduction and emissions improvement will result from an ATIS deployment, the system should have the following features:

   a) accurate information on link traffic conditions available with the shortest possible delay in communicating it to ATIS users;

   b) an accurate, reliable route planner with few limitations on link/route combinations; and--probably the key element on which ultimate success hinges--

   c) a convincing argument to the would-be purchaser of ATIS services that real, measurable benefits *will* accrue to him/her.

   The road network in which this system is to operate must possess alternative route options that are faster and not too much longer (significantly greater length can mean higher emissions) than the original route of choice, and which generally have excess capacity (mitigating the problem of diverted congestion).

4) Another way of stating point 3(c) is that the gap between system *potential* and actual system *performance* must be closed before the confidence of ATIS users can be won sufficiently to make them act consistently on ATIS guidance.

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APPENDIX G

RECRUITMENT OF VOLUNTEER DRIVERS FOR *ADVANCE* SUMMARY OF PROCEDURES FOLLOWED AND LESSONS LEARNED

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RECRUITMENT OF VOLUNTEER DRIVERS FOR ADVANCE SUMMARY OF PROCEDURES FOLLOWED AND LESSONS LEARNED

EXECUTIVE SUMMARY

The *ADVANCE* Project planned to engage 3,000-5,000 households in the field operational test of its in-vehicle dynamic route guidance system. To recruit this large number of volunteer drivers, a multi-step process was designed, including recruitability studies; solicitation methods; screening criteria and instruments; a computer database to manage recruitment, screen applicants, and generate communications; driver participation agreements designed to protect both volunteers and Project Parties; and driver selection, scheduling and training procedures.

The *ADVANCE* targeted deployment involved only 80 households and 127 drivers. These drivers were recruited using a reduced version of a process originally designed for the full-scale deployment. This paper provides an overview of *ADVANCE* recruitment procedures, their development and implementation. It is based on the series of technical documents produced in the design of recruitment procedures, screening instruments, participation agreements, as well as the experience and perspectives of some of the key actors in the *ADVANCE* recruitment process.

The lessons learned from this experience may be helpful to others engaged in the recruitment of volunteers to test new Intelligent Transportation System technologies. Those lessons include the following:

- Recruitability studies using focus groups and surveys were useful in the design of experimental conditions and driver participation agreements.

- Free publicity in various forms was sufficient for attracting over four hundred applicants for the *ADVANCE* targeted deployment. A larger field test would almost certainly demand a specific solicitation effort, probably involving advertising, either paid or free.

- A substantial amount of free advertising could probably have been secured if required.

- More aggressive solicitation might have been required to include under-represented groups (e.g., women and older drivers).

- Evidence from the targeted deployment of *ADVANCE*- suggests that application forms can be effective for screening drivers to meet specific criteria.

- Cooperation from the Illinois Secretary of State's office made it possible to check the driving

record of *ADVANCE* applicants to screen out drivers with poor records.

- That only 4% of otherwise-eligible drivers were rejected because of poor driving records suggests that application forms and publicity about the project led to self-screening, so that those obviously ineligible did not submit applications. It is also possible that the screening criteria were not so stringent as to exclude many drivers.

- By balancing concern for *ADVANCE* party liability against the interests of volunteer drivers, a fair and understandable driver participation agreement was crafted.

- Volunteer drivers were willing to accept reasonable responsibility for the in-vehicle equipment and, in the case of the *ADVANCE* targeted deployment, for the vehicles themselves.

- Personalized, hands-on driver training in the test vehicles quickly prepared volunteers for safe and efficient use of the *ADVANCE* system.

- An efficient and responsive computer database for contact management is essential for a field test involving large numbers of volunteer drivers.

- Designing and overseeing the recruitment process through a group representing all participating parties in the field test may be cumbersome but is essential to accommodate all important interests in and constraints on the recruitment process.

- Implementing the recruitment process with a knowledgeable and efficient single-point-of-contact agency may serve the volunteers well and preserve the resources of the technical staff.

- Critical details, such as dealing with leased vehicles, implications for and requirements on drivers' insurance, use of vehicles by persons other than those signing participation agreements, *etc.*, can take substantial time to negotiate but may become important in large experiments using volunteer drivers.

RECRUITMENT OF VOLUNTEER DRIVERS

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1.0 INTRODUCTION

The Advanced Driver and Vehicle Advisory Navigation Concept (*ADVANCE*) Project developed and field tested an in-vehicle Advanced Traveler Information System (ATIS) which was to provide route guidance to drivers based on current traffic conditions. A key element of the field test was providing *ADVANCE* in-vehicle systems for use by volunteer drivers in their routine, local trip-making. A major challenge in the implementation of this test was recruiting volunteer drivers to utilize the system.

The *ADVANCE* recruitment effort was designed to fill this need, to attract, select, and train sufficient drivers to meet test quotas. The sample of drivers needed to meet certain research and risk management criteria, to be of sufficient size, and, since *ADVANCE* was partially publicly-funded and thus subject to public scrutiny, to be the result of an unbiased process.

The recruitment effort was originally designed to meet a quota of drivers from 3,000-5,000 households using their own vehicles for periods up to two years. This presented a large and complex recruiting challenge. Ultimately, *ADVANCE* adopted a targeted deployment scheme, under which less than 100 households used the test vehicles. Still, many elements of the original recruitment process design were utilized under the targeted deployment. This effectively became a large prototype test of the original recruitment plans. As such, the resulting experience offers useful guidelines for the design of future Intelligent Transportation Systems (ITS) field tests using volunteer drivers.

1.1 Acronyms and Definitions

"*ADVANCE* Parties" refers to the four original partners in the project, The Federal Highway Administration, The Illinois Department of Transportation, Motorola, Inc., and the Illinois Universities Transportation Research Consortium (IUTRC), which for AD*VANCE* included Northwestern University and the University of Illinois at Chicago. Later in the project the partnership was expanded to five with the addition of the American Automobile Association.

Other terms and acronyms used in this document specific to the *ADVANCE* Project are defined in the System Definition Document #8020.ADV.06, available on the Internet at the following URL:

http://ais.its-program.anl.gov/

Acronyms are also spelled out in the report on first use.

1.2 Authors

(1) Joseph L. Schofer is Professor of Civil Engineering and Transportation at Northwestern University, specializing in transportation evaluation, market research, and planning. He is trained in Civil Engineering at Yale University and earned the M.S. and Ph.D. in civil engineering (transportation) at Northwestern. Under Schofer' s direction, Northwestern developed major components of the ***ADVANCE*** recruitment process. He represented IUTRC on the *ADVANCE* Steering Committee and served on the project's Technical Advisory Committee and Recruitment and Evaluation Subcommittees. Northwestern, through the Illinois Universities Transportation Research Consortium, is an *ADVANCE* Party.

(2) Thomas J. Nicarico is Senior Highway Systems Engineer with De Leuw, Cather & Company, the *ADVANCE* Project Systems Integrator. Nicarico graduated from the U.S. Naval Academy and holds an M.B.A. from the University of Chicago. He is a registered professional engineer with 30 years of experience working on highway and transit projects, testing, quality assurance and system safety. His most recent work has been in the field of project management. He held day-to-day responsibility for implementing the driver recruitment process for *ADVANCE*.

(3) Pamela Marston is Transportation Management Engineer with the Federal Highway Administration Region 3 (Baltimore) office, where she serves as Intelligent Transportation Systems (ITS) Coordinator for the Washington, D.C., area. She earned B.S. and M.S. degrees from the University of Virginia in civil engineering. She served as a technical specialist on the *ADVANCE* Project, where she was responsible for the development and implementation of driver recruitment procedures.

4) John Milano is Assistant Chief Counsel with the Illinois Department of Transportation (IDOT) in Chicago. He earned his bachelor's in political science from Northwestern University and his Juris Doctor from Notre Dame. Milano provides legal counsel to IDOT in many areas, including its Intelligent Transportation Systems programs. He served on the *ADVANCE* Recruitment Subcommittee, drafted the driver participation agreements, and contributed to the development of the overall recruitment process.

1.3 Intended Audience

This paper is written to inform scientists and managers in the design of ITS field operational tests involving the use of volunteer (unpaid) drivers.

1.4 References

A number of *ADVANCE* documents may provide useful background for understanding the context for and motivations of this report. In addition to those specifically cited within and listed in the endnotes, the following documents, available on the intemet at the URL listed in section 1.1, may be particularly helpful:

> *"ADVANCE"* - GOALS AND OBJECTIVES," Document # 8010.ADV.04, November 15, 1995.
>
> Joseph F. Ligas, PE, and Syd Bowcott, PE, *"ADVANCE* - Initial Deployment," ITS America, 1995.
>
> "Evaluation Program Plan," Document # 8400.ADV.03, July 17, 1995.
>
> Rick Laver, Joseph L. Schofer Chandra R. Bhat, Frank S. Koppelman, "Study Design for Evaluation of Market Response to *ADVANCE:* Objective, Data Collection and Evaluation Methodology," Document # ADV-MR-01, July 7, 1993.

1.5 Report Organization

This report begins with a brief background statement describing plans for the deployment of the *ADVANCE* field operational test and the use of volunteer drivers. It then proceeds through the steps in the recruitment planning and implementation processes approximately in the order in which they were applied in ADVANCE: recruitability studies, driver solicitation, screening criteria, database, contractors, personnel and committee organization, participation agreements, screening, selection, scheduling and training of drivers, and quantitative results of the *ADVANCE* Targeted Deployment.

2.0 PURPOSE

The purpose of this paper is to summarize experiences in the design and implementation of processes for recruiting volunteer drivers for *ADVANCE*. It builds on the technical reports prepared for the recruitment effort, cited in section 1.4 and in the body of the report, and it gathers the views of the key professionals involved in recruitment design. The results of the practical experiences with driver recruitment in *ADVANCE* may provide useful guidance for others involved in the large-scale use of volunteers in field tests.

3.0 FINDINGS

3.1 Background

The original intent of the *ADVANCE* recruitment effort was to identify as many as 5,000 volunteer households who would offer their personal vehicles for installation of the *ADVANCE* system, and who would subsequently use those vehicles in their normal travel to provide a meaningful operational test of the *ADVANCE* concept and its various features. Drivers were to be chosen to assure that they would make many vehicle trips within the test area, would be reasonably representative of the driving population and the region, and would be safe and trustworthy vehicle operators. As the *ADVANCE* Project proceeded, the quota of volunteer households was decreased from 5,000 to 3,000, and under the targeted deployment scheme ultimately adopted, less than 100 households were eventually selected to participate.. These households were provided with *ADVANCE*-equipped vehicles, rather than having the Mobile Navigation Assistants (MNAs) installed in their own vehicles, and they were permitted to drive *ADVANCE cars* for only two weeks, rather than the originally-planned 12-l 8 month test period.

Thus, the scale of the recruitment activity changed very substantially during the project, and the task to be accomplished was very greatly simplified. In this paper we will describe the tasks performed, evaluate the outcomes, and provide a perspective on what might have happened had the *ADVANCE* Project attempted to recruit 5,000 drivers for a l-112 year field experiment. A great deal of effort went into planning and preparing for a large-scale driver recruitment process for *ADVANCE*, but because of the targeted deployment scheme, only some aspects of this planned effort were actually implemented and most were not fully tested and utilized. The experience with the limited deployment suggests that in some dimensions (e.g., contact management) our plans and budgets may have been inadequate for the task of recruiting 5,000 drivers; however, the basic strategy seemed to be sound and provides a foundation for similar future efforts. Each of the major components of the recruitment process will be discussed in the sections below.

3.2 Recruitability Analysis

Two activities were undertaken to assess driver recruitability for *ADVANCE* prior to any actual effort to recruit drivers. These were two focus groups, in which 22 drivers residing in the study area participated, and a subsequent telephone survey involving 1,000 drivers in the study area. There were substantial differences in expectations on the part of *ADVANCE* Project Parties regarding the degree of difficulty likely to be experienced in efforts to recruit drivers. The recruitability analyses were intended to resolve some of those differences and provide a stronger foundation for the overall recruitment effort.

The focus groups' revealed that drivers were interested in the *ADVANCE* concept and were anxious to test it in their day-to-day driving. More important to the design of the recruitment process were some of the concerns drivers expressed about participation in the *ADVANCE* Project. Some expressed skepticism about the feasibility of the system itself, and others were concerned that the on-board system would be a distraction to their driving. Drivers wanted to avoid the risks associated with damage the ***ADVANCE*** system might cause to their cars, increased risk of theft and vandalism, and the potential of increased liability exposure. A few participants expressed concern about time and effort required to respond to evaluation surveys and about loss of privacy.

The telephone survey was constructed on the basis of the results of the focus **groups.**[2] The survey confirmed most focus group results and provided a stronger perspective on some of the obstacles to driver recruitment, findings which were to be of importance in the development of recruitment plans and the implementation of the narrower, targeted deployment recruitment effort.

The survey indicated that the willingness to participate in the ***ADVANCE*** field test was greater for men, persons who drove extensively, and persons with extensive experience with electronic devices such as personal computers. Survey results indicated that potential drivers were not particularly concerned about matters of loss of privacy due to ***ADVANCE*** monitoring and reporting requirements. They were, however, quite sensitive to the possibility that they might be exposed to personal liability or financial risks. Their reported willingness to participate in ***ADVANCE*** was considerably increased under scenarios in which the ***ADVANCE*** Project would accept responsibility for liability for use of the system, damage which might result to the ***ADVANCE*** system itself, and damage which might result to participants' vehicles.

Thus, the recruitability study showed that drivers were quite willing to participate as volunteers in the ***ADVANCE*** Project, but not at their own expense or increased risk. This suggests that it was important to protect the drivers, to indemnify them against incremental risks to the extent possible, and to inform them about their risks if participation was to be assured. All of this information was of value in the design of the recruitment effort, and particularly for the development of driver agreements, both in substance and in language. The recruitability analysis formed the basis of much of the debate that went into-the development of these documents, and the results can inform other ITS field tests in which volunteers are to be recruited to test such systems. The recruitability studies were a cost-effective way to gain these insights into the challenges of volunteer driver recruitment.

3.3 Soliciting Candidate Drivers

Original plans for the full deployment of ***ADVANCE*** defined a set of solicitation procedures which included both free and paid advertising in local and regional media **outlets**[3] Well before a decision was made to refocus ***ADVANCE*** on the targeted deployment, with volunteer drivers from less than 100 households, a considerable amount of publicity about ***ADVANCE*** appeared in electronic and print media throughout the region. This attracted a substantial amount of attention and many volunteers called the Project Office and the offices of other ***ADVANCE*** Parties to volunteer as test drivers. The names of these volunteers were recorded, and this group, which came to the project as a result of unpaid publicity, provided the source of drivers used for the targeted deployment. Over 400 drivers (households) formally applied to participate, and from this group, drivers from 80 households ultimately drove *ADVANCE* vehicles as a part of the targeted deployment.

While free and serendipitous dissemination of information about the *ADVANCE* Project provided a sufficient number of recruits for this limited deployment, a more aggressive and highly structured solicitation scheme would almost certainly have been required to attract several thousand candidate drivers for a larger experiment. To support the gradual ramp-up of the fleet as originally planned for *ADVANCE*, which involved a period of twelve months or more to install all of the in-vehicle systems, several rounds of solicitation would have been necessary to maintain a steady stream of candidate recruits for the field experiment.

Metro Traffic, a for-profit distributor of real-time traffic information, had committed to supporting this effort through free broadcast announcements had *ADVANCE* gone to the full-scale deployment scheme. *ADVANCE* also contracted with a public relations consultant, who supported the work of the Public Information Subcommittee. Under a full deployment, this combination of resources would have been devoted to generating widespread public interest in the project through free news coverage, and perhaps additional cooperative relationships such as that proposed with Metro Traffic. Together these actions likely would have reduced the need for paid advertising to solicit volunteer drivers. Still, a systematic outreach as proposed in the original recruitment **plans**[4] would probably have been necessary to assure reasonable sample of drivers by gender (particularly since men were more inclined to participate than women), age (because younger, computer literate people were more interested than others), and location within the study area. The small sample of 80 households which actually participated in the project, while adequate for the purposes of targeted deployment, was too narrowly focused to provide a strong basis for generalization; a larger scale experiment would have demanded a more balanced sample.

3.4 Screening Criteria.

A series of criteria were defined for selecting drivers and vehicles for participation in *ADVANCE*. Under the targeted deployment, the driver criteria were still applicable and were used to select participants; vehicle criteria were irrelevant because *ADVANCE* supplied equipped vehicles to participating drivers. Still, it is useful to consider the implications of the vehicle criteria and what they might have meant under a larger scale deployment.

Household requirements for participation **were:**[5]

- must own or lease a vehicle available for installation of the *ADVANCE* MNA;

- must reside in the *ADVANCE* test area;
- must not present a risk due to driving record (as determined by self reports and a check of Illinois Secretary of State driving records);
- must not present a risk due to medical problems (based on self reports);
- must be an active trip maker, based on drivers' self report of weekly travel characteristics converted to an aggregate score for each applicant household.

Criteria were also established for vehicles eligible to participate in the project. These were:

- primary driver of the vehicle must be 25 years of age or older (associated with vehicles since commonly vehicles are assigned to specific drivers in the household);
- vehicles with passenger-side - airbags were ineligible due to MNA installation conflicts;
- vehicles older than 8 years were ineligible (most of these did not have the electronic interfaces required by the MNA);
- owned or leased vehicles likely to be replaced within two years were excluded to avoid the need for extra removals and installations during field tests;
- vehicles with non-metallic or removable tops were excluded because of problems associated with antenna installation; and
- vehicles were excluded if they were not covered with liability insurance at or above the level of $100,000 per person and $300,000 per accident. This criterion was intended to excluded "underinsured" drivers, on the principle that if they were involved in an accident, the likelihood of *ADVANCE* Parties being sued would be greater. The $100,000/$300,000 level was selected based on discussions with insurance industry representatives to provide the project with some protection while not excluding large numbers of candidate driver?.

Experience with the targeted deployment suggests that application forms and advance publicity were effective at discouraging drivers with poor safety records from applying to participate in the project. It was not difficult to find volunteers living in the test area, and most applicants were very active trip makers.

While a reasonable number of females and older drivers volunteered to participate in the targeted deployment, it is likely that it would have been difficult to meet gender quotas for a larger-scale deployment. One of the phenomena observed among the 80 households which participated in targeted deployment was that in households including male and female volunteer drivers, the male drivers tended to dominate the use of the vehicle. In order to get reasonable gender balance, substantial outreach might have been necessary in a large-scale deployment, and even then meeting the quota might have been a challenge. The same problem is likely to have occurred for older drivers, necessitating directed outreach to senior centers and other places where the likelihood of contacting older drivers would be substantially increased.

Restrictions on vehicle types were revealed incrementally by the system designers to the team developing the recruitment criteria and procedures. It appeared that several of the problems associated with particular vehicles (e.g., location of driver- and especially passenger-side airbag deployment zones, soft top vehicles, fiberglass body vehicles, etc.) were not fully anticipated by designers early in the process, and were only determined as the design and experimental vehicle installations progressed. This presented a challenge to the design of the recruitment effort, as it was necessary to revise criteria and household screening instruments (adding questions about vehicle configurations) at several points along the way. Some of the inefficiency might have been mitigated through better communications between designers of the in-vehicle system and those involved in recruitment design, although both groups were represented at monthly Technical Advisory Committee meetings. However, the natural division of labor did not encourage members of the in-vehicle system design team to participate actively in the recruitment process until fairly late in the effort.

Restrictions due to airbag deployment zones, particularly but not solely for passenger-side airbags, might have presented a major obstacle in recruitment of volunteers for large-scale deployment, since airbags became a virtual standard in new cars during the period that the *ADVANCE* system was being designed and developed. Ultimately, Motorola design engineers came up with installation options that would permit the inclusion of many cars for which information on airbag deployment zones was made available by manufacturers. Certain airbag designs, and difficulty gaining access to airbag deployment zone details for other vehicles, might have forced exclusion of some vehicles from a large-scale deployment, and thus could have hampered recruitment.

3.5 Recruitment Database

A database management application was developed by Northwestern University to store data on *ADVANCE* driver applicants, screen those applicants according to established criteria, automatically generate a variety of letters to those applicants, and provide routine reports to the driver recruitment team.' The database as developed eventually worked sufficiently well to support the targeted deployment. A variety of development and implementation problems were experienced that ultimately would need to have been solved had the larger-scale deployment been implemented.

A principal difficulty was that the Northwestern team had limited experience in the development of large databases. In retrospect, it would have been more efficient and effective to contract out the development of the database to a software applications house with a management, rather than a research orientation. However, at the time when the database was needed, there was considerable pressure to accelerate the development to keep on schedule, and to do that through Northwestern University rather than adding another sub-contractor to the program. Neither the Northwestern team nor the Project Office anticipated the complexities associated with the development of the database large and flexible enough to manage the recruitment of 3000-5,000 drivers.

Based on the experience of the Project Office, the systems integration contractor (De Leuw, Cather & Company), and the recruitment contractor (The Blackstone Group - see section 3.7), scaling up to this larger application would have been difficult. The system would have had to have the capacity for l0,000-12,000 records, which would have been entirely feasible in the software and hardware environment chosen (Paradox for Windows 5.0 on a 486 or higher platform). However, processing speed would have been quite slow in this context. With a much larger number of applicants and recruits in the database, the contact management tasks (e.g., letters to applicants and participating drivers) would have been extensive, and the software as written may not have been able to sustain this load effectively. A software platform that was more oriented toward contact management would probably have been required, and whether this could have been integrated with the database or designed as a separate component is not clear. What is clear is that the overall process of entering, analyzing and managing the data for 5,000 drivers (recruited out of a much larger base) would have been large and complex.

3.6 Recruitment Subcommittee

A Recruitment Subcommittee (RSC), a subcommittee of the *ADVANCE* Technical Advisory Committee, was established in March of 1994 to bring together those parties most concerned with driver recruitment: Illinois Department of Transportation (IDOT) Chief Counsel's Office, *ADVANCE* Project Office, American Automobile Association (AAA)-Chicago Motor Club, Northwestern University (part of the Illinois Universities Transportation Research Consortium), Motorola and Argonne National Laboratory, which was soon to become evaluation manager. John Milano of the IDOT General Counsel's Office led the effort to draft driver participation agreements. Jonathan Lehrer of the AAA-Chicago Motor Club, whose background is in communications and public relations, brought important skills to the development of screening forms, participation agreements, and public information plans.

The RSC met approximately biweekly, and became the key forum for negotiating recruitment criteria and procedures among the parties. The diversity of skills and knowledge within the subcommittee amplified its creative abilities. Considerable time was spent within the RSC refining driver participation agreements. The subcommittee received progress reports on the various recruitment tasks and provided consensus guidance for planning and implementing the overall recruitment process.

3.7 Recruitment Contractor

From the early stages of the design of the recruitment process, the Northwestern team recommended that a recruitment contractor be hired to manage contacts with applicants and recruits and to operate the database. It was clear that deployment at the level of 5,000 vehicles would have required substantial contacts with the driving population, and the neither the Project Office nor the University was in a position to do this job efficiently. The task was sub-contracted through De Leuw, Cather to The Blackstone Group, a firm that had good capabilities in survey data collection and entry. The tasks handled by the recruitment contractor even under the targeted deployment were important, for they provided both volunteers and project management with a single point of contact for recruitment, At the scale of 3,000 participating vehicles, it would have been essential to have an outside contractor handle the day-to-day responsibilities for recruitment. The task at this larger scale would have demanded full-time attention from one or two middle managers.

The recruitment process was somewhat complicated by the necessarily overlapping roles of the various participants:

> <u>The Project Office</u> had responsibility for oversight (including schedule adherence), and was appropriately concerned about the form and content of all communications with prospective drivers, and occasionally intervened to handle special, sensitive applicant cases. For the sake of efficiency, the Project Office communicated directly with The Blackstone Group to move recruitment tasks along.
>
> <u>Northwestern University</u> developed the technical design for the recruitment process and the database. Because of the evolution of the project itself and its targets, a variety of aspects of the recruitment and database design were evolving while The Blackstone Group was implementing the database for the initial set of applicant drivers. Northwestern did not supervise the work of Blackstone, but was occasionally called in to intervene and/or to **solve** problems. Northwestern communicated primarily with the Project Office and the systems integration contractor rather than Blackstone.
>
> <u>De Leuw, Cather & Company</u> the systems integration contractor, provided general support to the Project Office and played a pivotal role in the implementation of the recruitment effort, effectively having day-to-day responsibility for the process. The Blackstone Group was a sub-contractor to De Leuw, Cather. Had the project gone to full-scale deployment, De Leuw, Cather would have had to provide additional staff support because both the recruitment tasks and their other responsibilities would have grown substantially. The role of an outside recruitment contractor would have become critical to success of the effort.
>
> <u>The Blackstone Group</u> maintained a local post office box which served as the advertised address for use by ***ADVANCE*** volunteers. Blackstone received driver application forms and entered them into the database, and served as primary contact with the Illinois Secretary of State's office to check applicants' driving records.

Blackstone was tasked to begin processing applications using the database software before Northwestern had completed development, testing and documentation of the database. This was necessitated by schedule requirements. On a number of occasions Blackstone made modifications to the database software in an effort to correct problems, real or perceived (as a result of lack of software documentation). These changes confounded Northwestern's continuing development of the database, because at times it was unclear what the latest version was, or what changes had been implemented. Stronger, more timely configuration control would have been beneficial at this point, with responsibility centralized at Northwestern. Eventually conflicts caused by the simultaneous use and development of different versions of the database were resolved. Some of this might have been avoided if the database had been completed more quickly, and if configuration control were maintained so that modifications could be coordinated. In a larger scale deployment, these bugs would have been worked out, but it would have taken a while for the database application to get up to speed.

3.8 FHWA Assistance

In March of 1994, about halfway through the development of the recruitment process, the Federal Highway Administration (FHWA) assigned Ms. Pamela Marston to the ***ADVANCE*** Project for a period of about nine months. Marston was asked to oversee the development of the recruitment process. She devoted nearly full-time attention to the development of the recruitment effort. She became an effective, driving engine in the effort to pull together the various components of the recruitment process that had already been developed. She also explored insurance coverage issues and worked with auto leasing organizations to develop procedures for including leased vehicles in ***ADVANCE*** while limiting the risks to the project of loss of in-vehicle units due to vehicle repossessions. She developed driver safety screening criteria and worked with the Secretary of State's office to arrange for checks of driving records of ***ADVANCE*** applicants.' She was influential in finalizing the application and screening forms and the construction of the agreement between the ***ADVANCE*** Project and participating drivers. Ms. Marston's stay was extended to include the beginning of the implementation of the recruitment process.

Had the project gone ahead to a full-scale deployment of 3,000-5,000 vehicles, not having a member of the professional staff who could give nearly full-time attention to recruitment would have been a major obstacle to progress.

3.9 Driver Participation Agreements

It was essential to the protection of both parties that a formal agreement be created and executed between each participating driver and the ***ADVANCE*** Project. Driver interests included protection against liability in the case of accidents or damage to the ***ADVANCE*** equipment and privacy of personal information. ***ADVANCE*** interests included assuring that drivers would be effective participants and provide the needed data; protection against liability risks from actions of drivers; protection of ***ADVANCE*** equipment; assurance that drivers would operate vehicles safely; and **in** the case of the targeted deployment, protection of the ***ADVANCE*** vehicle itself.

The driver agreement was drafted by John Milano, the IDOT attorney, and reviewed and revised over a number of cycles by the Recruitment Subcommittee. Initial drafts of the agreement emphasized the liability concerns of the ***ADVANCE*** Parties; gradually, as the agreement evolved, ideas derived from the original recruitability studies, as well as views provided by the representative of the AAA, helped to produce a more balanced agreement.

The agreement evolved in two dimensions. First, substantively, protections for ***ADVANCE*** Parties were balanced with precautions and concerns for the interest of participating drivers. Second, the agreement was gradually revised from a rather formal, legal-style to a more informative, layman's language style. The final form of the agreement planned for the full deployment is shown in Attachment I. This is quite clear and readable, written in terms that are easily understood by a typical driver. This document may serve as a model for driver participation agreements in future ITS field tests, allowing other experimenters to benefit from the substantial and lengthy effort that the ***ADVANCE*** Project went through to develop it. It reflects the findings from the recruitability studies, that drivers were concerned about protecting their own interest, and that those concerns would likely have a substantial influence on their willingness to participate in the experiment.

Experiences with drivers in the targeted deployment as well as with paid drivers who participated in other ***ADVANCE*** evaluation tests, suggest that it is especially important that participants, whether paid or not, understand what is expected of them, appreciate the nature and limits of the risks that they take, and feel that they are appropriately and fairly informed. It is important to recognize that volunteer drivers, or paid, short-term employees who are driving to collect evaluation data, are essential contributors to ITS field tests. Project managers should pursue reasonable means to eliminate obstacles to the participation of such volunteers in the form of liability risk, penalty fees, and complex agreements and documentation. This suggests that the experimenters (and participating agencies and firms) themselves must be willing to take more of the risks in order to get the data necessary to evaluate ITS field tests.

A simpler agreement was prepared by IDOT to use in the targeted deployment. This is included as Attachment II.

3.10 Screening of Applicants

Two forms were developed for applicant screening, the first to do the basic cut, eliminating obviously unacceptable drivers (residence out of the study area, unacceptable vehicle, poor driving records, medical problems). This is a short form (included as Attachment III), designed strictly for self-reporting, and intended to discourage unqualified drivers from pursuing participation in the ***ADVANCE*** Project. The second, longer form (Attachment IV) asked more detailed questions about household characteristics, vehicle ownership and characteristics, driving habits, and a variety of specific driving record and medical problems. This was the original screening form and it was designed to serve both as an application form and as the sole basis for selection of drivers for participation in or exclusion from the project. The short form was developed later in the process to serve as a self-screening step to select out obviously unqualified households without requiring them to complete the longer form.

Under the larger-scale deployment, it would have been useful to use both of these forms, because the short form would have served to be the primary screening step for the' majority of driver applicants, while the long form would have provided the detailed data necessary for selection decisions. However, for the smaller scale deployment, it is not evident that there was a particular value in having a two-stage screening. It may have been sufficient to use only the long form because all questions asked on the short form were repeated on the long form, while the latter had many more questions which were essential for the screening and selection process. Having two forms added to the challenge of developing the database, amplified the data entry effort, and added the requirement for an additional set of communications with drivers who were applying to participate.

The screening process as it was actually implemented under the targeted deployment is described in the following paragraphs.

Both screening forms functioned well, applicants were able to complete them, and they provided needed information to screen and select drivers. Most applicants completed the short form, which screened them on five criteria. Upon receipt of completed forms, basic data, e.g., name, address, telephone numbers and the five responses, were entered into a database program, screened on pass/fail responses, follow-on correspondence was generated, and tracking records for both applicant and associated correspondence were created. Those who satisfied this basic screening were invited to complete the four-page long application form.

Data were manually entered into the database by The Blackstone Group, which maintained the recruitment database and processed all related correspondence. The database could generate form letters for all the normally-occurring situations resulting from applicant responses, and replies were automatically sent by Blackstone to applicants. Blackstone also contacted applicants by telephone for any incomplete information needed for the screening process. Such individual contacts would have complicated a larger-scale recruiting process, demanding either more person-hours or a large enough pool of applicants to allow us to discard incomplete applications without personal follow-up. Of course procedures (such as form letters describing missing items) would be needed to avoid the appearance of an unfair rejection process.

From the perspective of efficiency, reducing or eliminating this need for individual contact would be desirable. However, all ***ADVANCE*** parties, and especially the IDOT Project Office, were motivated to maintain a high quality relationship with the public, in part to ensure recruitability, but also to avoid public image problems. In the targeted deployment, it was easy to decide in favor of more direct, personal treatment of applicants. At large scale, it might have been necessary to adopt a different policy toward dealing with applicants.

The full application form provided information on household driving patterns, more specific driving history and other demographics. These data were entered in the database program, compiled, compared against criteria and sorted by pass/fail criteria. Driving patterns were weighted and scores compiled. The form also required listing of household driver license numbers, which were checked against the Illinois Secretary of State's (SOS) driver records for those applicants who satisfied all other requirements. To accomplish this last check, because of privacy concerns at SOS, it was necessary for a special contractual agreement to be executed between the recruitment contractor (Blackstone) and SOS authorizing specifically-designated contractor personnel to acquire and use this information, Only normally-available information on driving records was provided; other personal information was excluded. Information was exchanged between Blackstone and SOS by fax and modem, and was entered into the database manually. Driving record checks were screened according to the violation list shown in Attachment V; any of these violations was grounds for exclusion. This violation list was developed with the guidance of SOS representatives.

Cooperation of SOS was essential to assure a source of valid information on driving records of ***ADVANCE*** volunteer drivers. This cooperation was negotiated by Ms. Marston and Project Office (IDOT) staff. SOS required that the project and its recruitment contractor (which maintained direct contact with SOS) agree not to distribute this information elsewhere, or to use it for purposes other than driver screening. SOS agreed to waive the fee for record searches. In other states such information may not be available, or such a cooperative relationship so readily established. Under such circumstances the challenge of evaluating the driving record of volunteers will increase greatly.

A less-desirable alternative for evaluating driver characteristics was used to screen for medical and perceptual problems: self-certification. Applicants were asked to certify that they had no such problems on the screening forms (see Attachment IV, questions 40-42). This does not assure the validity of the information, but it does demonstrate on the part of the experimenters a good faith effort to screen out problem drivers.

Finally, those applicants who satisfied all criteria were invited to sign the Participant Agreement. This document delineated responsibilities of both the driver to the project and the project to the driver. Upon receipt of a properly executed agreement, the applicant became a candidate ***ADVANCE*** driver.

The screening process was supported by the use of the Paradox database application, which stored, screened and sorted the information associated with the hundreds of applications received. The database generated routine status reports to support the recruitment process and customized form letters in response to each application received. To have attempted such a process without this computerized support would have made an already labor intensive process much more time consuming and tedious.

The database was also used to identify missing information and to check entered data needed to verify that it was correct. Routine counts of various categories of data entered, processed and output gave clues about such input errors, augmenting tedious entry-by-entry checks.

3.11 Driver Selection

Under the large-scale deployment for ***ADVANCE*** a pool of eligible applicants was to be selected by the automated application of selection criteria within the ***ADVANCE*** database. This pool was then to be presented to the Recruitment Subcommittee, representing the ***ADVANCE*** Parties, which would make the final selection, balancing a variety of sampling and public policy issues in the choice.[9] Applying this manual selection process at the scale of 3000-5,000 recruited drivers would have been a substantial challenge. Probably, once the procedures had been worked out within this subcommittee, it would have been possible to delegate the process to a single professional staff member. Such a delegation would have been essential under the large-scale deployment. It is likely to have been feasible, since at the level of 3000-5,000 drivers, a balanced distribution of volunteers could be achieved by virtue of the large sample size. At the beginning of the ADVANCE selection process (under targeted deployment), more thoughtful selection of drivers was appropriate at a time when public and press scrutiny was at its highest. In a much larger field test, selections might be made by the screening software and a designated individual.

Under the targeted deployment scheme, lists of acceptable candidates were compiled by a number of demographic categories, with emphasis on the travel intensity scores to find the most active drivers. The initial selection of drivers was made by the Recruitment Subcommittee. Later, when additional selections were needed to fill in for unavailable drivers, drivers were selected on the basis of the following priorities:

1. availability of the drivers from the first group of selectees;.
2. availability of the drivers from the initial pool of candidates not in the first group of selectees;
3. availability of drivers from those candidates who had previously declined the offer to be a driver due to schedule conflicts; and lastly
4. availability of candidates from subsequent (new) applications.

Within each of these groups, travel intensity score remained the primary selection factor, subject to availability.

Under targeted deployment, a simplified Paradox program was developed and used to track driver processing. The full program was not utilized since its very large database prolonged this simpler tracking task with its smaller data set.

3.12 Driver Scheduling

Even under the targeted deployment, coordination of vehicle availability, driver availability and test schedules during the Familiar Driver Test" phase proved to be labor intensive. Selected drivers eager to participate often were unavailable when the project had scheduled them, requiring other eligible drivers to be queried and scheduled. It was necessary to confirm schedules individually with selected drivers, not only by letter, but also by telephone a day or so before an individual was scheduled to receive the vehicle; making contact became a challenge at times. We chose not to minimize this administrative burden by "over-scheduling" drivers for specific test periods, since to have done so would have required cancelling over-scheduled individuals on short notice, and this may have promoted ill-will toward the project.

Under a larger deployment, the scheduling task would have been particularly challenging. It would have been almost a necessity to over schedule drivers because of the high likelihood that no-shows would have introduced delays in the implementation of the field test. Additional personnel and more advanced support software would probably have been essential to accomplish this task. Motorola, as the in-vehicle system installer, and the Project Office developed plans for a cooperative scheduling procedure utilizing the recruitment database. These were not implemented under the targeted deployment.

3.13 Driver Training

Because households participating in the Familiar Driver Test had *ADVANCE* vehicles for only two weeks, it was important to assure that drivers were sufficiently well-trained in the use of the *ADVANCE* system that they could be effective test participants from the moment they drove away from the Project Office in their test cars. As a result, special emphasis was placed on driver training. Drivers were given a 20-30 minute briefing about the *ADVANCE* Project and the operation of the *ADVANCE* system in the Project Office. Then each household was given 30-40 minutes of hands-on training in an *ADVANCE* vehicle by a member of the project staff with substantial experience in the operation of the in-vehicle system. This appeared to be a particularly effective process, and it was quite workable for the targeted deployment.

For a large-scale deployment, driver training at this level of intensity would have required a substantial commitment of personnel. Instead, much training was to be accomplished by drivers themselves using specially-prepared training videos and documents. The likely result would have been that drivers would have experienced a start-up period of a week or so once they received the in-vehicle system before they could use it efficiently and safely. This is likely to have generated a substantial number of calls to the planned *ADVANCE* toll-free Help Line (not implemented under targeted deployment) or to the Project Office. The more intensive training scheme used under targeted deployment resulted in very few calls for help in the use of the system by participating drivers.

In future experimental deployment of ITS systems, it is important to recognize the value of at least a brief hands-on training session for new drivers to assure their safety and efficiency. The personnel requirements for doing this could be substantial; the consequences of not providing such training would likely include decreased test efficiency, increased hazard, and substantially increased calls to whatever help service is provided to participating drivers.

3.14 Results of Targeted Deployment Screening and Selection

Figure 1 summarizes the results of the screening and selection process under the targeted deployment. Four-hundred-eleven short application forms were received based on news stories and various forms of free publicity. Of these, 112 (approximately 25%) of the applicants were found to be ineligible, primarily because they did not live in the study area, or their vehicles did not meet *ADVANCE* requirements. Of the 299 households who were informed that they were eligible to participate in the project, only 177 (59%) returned the full application form. We do not know why the other 122 did not return the form, but considerable time (almost 2 years) elapsed after the initial publicity and before the targeted deployment proceeded. Had there been a wave of publicity about the targeted deployment, it is likely that some of these 122 would have been reminded to return their application forms. Furthermore, no effort was made to follow up on these drivers to encourage them to return their forms, because there was no need for them under the targeted deployment plan. Had there been a need, under a larger-scale deployment, follow up would have been feasible (the

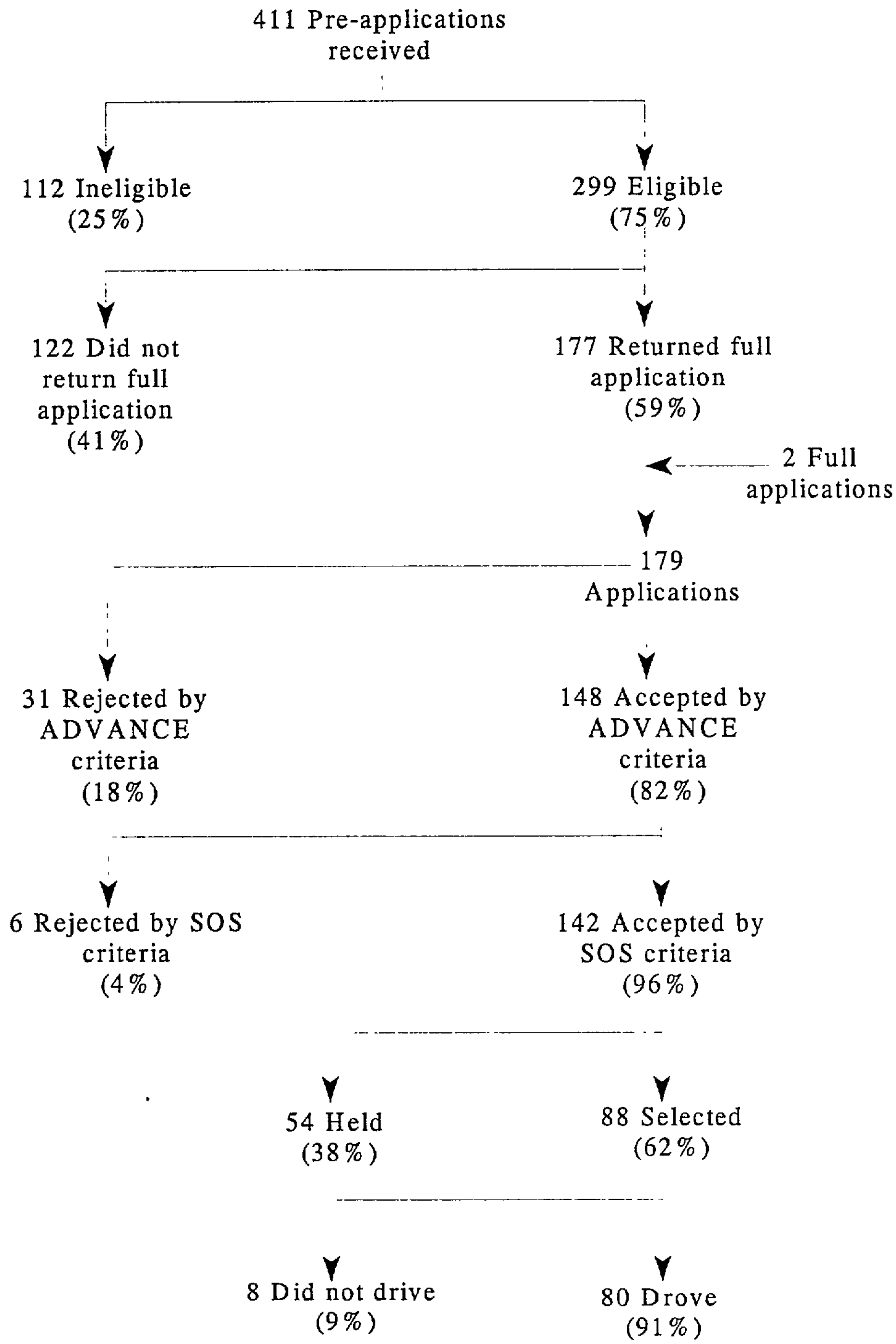

Figure 1. Screening Results for Targeted Deployment

database could produce reminder letters), and is likely that a substantial number of these non-responding drivers would have come back into the *ADVANCE* process.

Of the 177 drivers who returned their full applications, and two others who submitted full applications but had not submitted pre-application forms, only 31 (18%) were rejected according to the specific *ADVANCE* selection criteria. The driving records of drivers from 148 households were checked by the Illinois Secretary of State's office. Only six (4%) were rejected on the basis of SOS criteria. That 96% of the drivers passed the SOS test suggests that advance publicity and screening form questions discouraged ineligible drivers from applying for the program (or perhaps the screening criteria were not too stringent relative to applicants' driving performance). This is a favorable result, for it suggests that publicity and screening instruments can serve to encourage desired drivers to apply to the program while discouraging those who are ineligible. Eighty-eight households were selected to participate in the targeted deployment; 54 others were found to be eligible but were held for potential involvement if that became necessary because of scheduling problems with the first set of selected drivers. Selection of the 88 to participate was based on travel intensity scores, as well as the desire to achieve a reasonable mix of genders and ages in the sample. Near the end of the targeted deployment, the dominant criterion used for selecting out of this pool of eligible drivers was availability and ability to fit within the ADVANCE test schedule.

4.0 SUMMARY

Volunteer drivers were essential to the success of the *ADVANCE* evaluation. The drivers participating in the *ADVANCE* targeted deployment (127 drivers from 80 households) were recruited using a reduced version of a process originally designed for the full-scale deployment involving 3,000-5,000 vehicles. The main components of this process were:

- recruitability analysis
- solicitation
- screening
- participation agreements
- selection, scheduling and training

In the targeted deployment, these steps were successful, producing an ample number of qualified drivers and fulfilling sampling quotas. Among the lessons learned were the following:

- Recruitability studies using focus groups and surveys provided useful guidance in the design of experimental conditions and driver participation agreements.
- Press coverage and word-of-mouth were sufficient for attracting over four hundred applicants for the *ADVANCE* targeted deployment. A larger field test would have required a specific solicitation effort, probably involving advertising, either paid or free.
- The *ADVANCE* experience suggests that a potentially significant amount of free advertising could have been secured if required.
- More aggressive solicitation might have been required to include under-represented groups (e.g., women and older drivers).
- Evidence from the small-scale targeted deployment of *ADVANCE* suggests that application forms can be effective for screening drivers to meet specific sampling criteria.
- Through cooperation from the Illinois Secretary of State's office, it was possible to check the driving records of all *ADVANCE* applicants to screen out drivers with high traffic convictions rates and those convicted of serious driving offenses.
- That only 4% of otherwise-eligible drivers were excluded because of their driving record may indicate that application forms and publicity about the project encouraged drivers to self-screen, so that mainly those likely to be eligible actually submitted applications. It is also possible that the driving record screening criteria were not stringent enough to exclude many drivers.
- By balancing concern for *ADVANCE* party liability against the interests of volunteer drivers, a fair and understandable driver participation agreement was crafted; this could serve as a model for use in other ITS field tests.

- Drivers were willing to sign a participation agreement accepting reasonable responsibility for the in-vehicle equipment and, in the case of the *ADVANCE* targeted deployment, for the vehicles themselves.
- One-on-one driver training in the test vehicles quickly prepared volunteers for safe and efficient use of the *ADVANCE* system.
- An efficient and responsive computer database for contact management would be essential for a field test involving a large number of volunteer drivers.
- Designing and overseeing the recruitment process through a group representing the interests of all participating parties may be cumbersome but is essential to accommodate all important interests in and constraints on the recruitment process.
- Implementing the recruitment process with a knowledgeable and efficient single-point-of-contact agency, preferably not the technical professionals developing the field test, may serve both the volunteers and technical staff well.
- Small details, such as dealing with leased vehicles, implications for and requirements on drivers' insurance, use of vehicles by persons other than those signing participation agreements, etc., can take substantial time to work out but may become important in large experiments using volunteer drivers.

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9. Pierre Odent, Joseph L. Schofer and Frank S. Koppelman, Op. Cit.

10. Familiar Driver Evaluation Test Plan," Document 8462.ADV.00, June 14, 1995.

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Attachment I. Initial Driver Participation Agreement

(Mock-up only; the section describing ADVANCE
was not completed and is filled with random letters)

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ADVANCE

GENERAL INFORMATION ABOUT ADVANCE

Keep this information in the vehicle
with the *ADVANCE* Owner's Manual

WHAT IS IVHS?

ADVANCE is part of a nationwide program to develop and test Intelligent Vehicle Highway Systems (IVHS). which apply emerging technologies in such fields as information processing, communications. control and electronics to surface transportation needs. If these technologies can be effectively. implemented and deployed, the public will be able to use the nation's highway infrastructure and energy resources more efficiently by making more informed choices about travel and route alternatives.

Successful deployment of IVHS services and systems will achieve improvements in safety, mobility, and productivity, and reduce harmful environmental impacts, particularly those caused by traffic congestion.

WHAT IS ADVANCE?

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SAFE DRIVING

when you sign the Agreement for Participation in ADVANCE. *you* agree that it is your responsibility to operate your vehicle in a safe manner.

You *must* pay attention to the road in the same manner as you always have done when driving. You must avoid the temptation to follow your vehicle's location or progress on *the ADVANCE* in-vehicle screen. The screen has been designed so that when the vehicle is in motion, a quick glance is all that will be necessary to get the information you need.

For safety *reasons, the ADVANCE unit will* not allow you to program a new destination while the car is in motion. Do not fiddle with any of the buttons on the unit unless the car is stopped in a safe position.

INFORMATION KIT

By *the time the ADVANCE* unit is installed in your car. you should have received a variety or printed information which you should review as soon as you can. This material should include:

- Signed copy of *the ADVANCE Driver* Participation Agreement.
- Mobile Navigation Assistant (MNA) Operator's Manual
- *ADVANCE* instruction card for visor
- AAA-Chicago Motor Club Membership Kit, including a handbook explaining your membership benefits.

THIS IS AN EXPERIMENT?

It's important to keep in mind that you are enrolled in a test project. A great deal of resources have been devoted to creating equipment and systems that work effectively. But there likely will be occasional glitches. Read the information below for advice on dealing with apparent mechanical problems. Non-mechanical Problems should be noted and reported *to the ADVANCE Project Office* (708/705-4800)

PROBLEMS WITH THE ADVANCE UNIT

If at any time you experience problems with *your ADVANCE unit* please contact the *ADVANCE* Help Center at 1-800-000-0000 The Help Center staff will attempt to give you advice over the phone to solve the problem. If the problem cannot be fixed over the telephone, you will be referred co an authorized Motorola Service Center for problem *resolution.*

No one other than a Motorola Authorized repair person may attempt any repairs to the *ADVANCE* unit.

IF THE CAR NEEDS REPAIRS

The *ADVANCE* equipment installed in your vehicle will not affect any mechanical operation of your vehicle. Any normal maintenance or repairs will not be affected by the equipment The equipment, however, is bed into the electrical system of your vehicle. It is fuse-protected and will not harm any existing electronic equipment in your vehicle. *A* sticker *on the ADVANCE* computer in the trunk of your vehicle displays a telephone number that your mechanic can call with any questions regarding the unit

IF YOUR CAR IS INVOLVED IN A COLLISION

You always should notify your insurance carrier and the police if your vehicle is involved in a collision. In addition. you must *notify the ADVANCE Project Office* of any collisions involving *ADVANCE*-equipped vehicles.

An inspection by Motorola Authorized personnel will determine whether the *ADVANCE* components sustained any damage. Depending on the circumstances of

GENERAL INFORMATION ABOUT ADVANCE

the collision, the Project Manager may decide that the ADVANCE quipment should be removed from your ear.

DRIVERS CAN-BECOME INELIGIBLE TO PARTICIPATE

Even *after ADVANCE is installed in your* car, you could become ineligible to participate in *the program. You must notify the ADVANCE* Project Office of any of tbe conditions listed below. The Project Manager will decide whether you can remain in the program under the circumstances.

- You fall victim to a medical condition that would make you a less reliable driver.

- You or someone in your household is convicted of a serious traffic offense-such as driving under the influence. or leaving the scene of an accident.

- Your household *moves* its residence outside of the official test area (northwest Chicago and northwest suburbs).

SELLING OR TRANSFERRING TITLE TO YOUR VEHICLE

Because *the ADVANCE* equipment can be removed only by Motorola Authorized *personnel, you must notify the ADVANCE Project office* as soon as you begin planning to sell or otherwise transfer title to your vehicle, or move outside the test area.

OTHER DRIVERS

The person whose name appears on the *ADVANCE* Driver Participation Agreement in tie boxes marked "Primary Driver" is responsible for the safe usage of the *ADVANCE system.*

Any other driver expected to drive the vehicle *must be listed on the ADVANCE Driver* Participation Agreement The primary driver must instruct any other drivers regarding the safe operation of the unit.

TRANSFER OF "PRIMARY" DRIVER

You must notify the *ADVANCE* Project Office if someone else in your household becomes the primary driver of the ADVANCE-quipped vehicle. This situation would occur, for example. if the primary driver gets a new car and the ADVANCE-equipped vehicle is transferred to another member of the housebold.

The reason for this requirement is that project researchers are studying characteristics of the *various drivers using the ADVANCE units.*

DRIVING OUTSIDE THE TEST AREA

The northwest suburban area of Chicago is the only place where the *ADVANCE* unit will take real-time traffic and road conditions into consideration when planning a route. However. the navigational component of *ADVANCE* (without real-time traffic conditions) will work throughout the greater Chicago arca.

If you drive outside of the Chicago area, the *ADVANCE unit will* not function. This condition will cause no damage to the unit and it is not necessary to turn the unit off before driving outside the area.

COSMETICS

The *ADVANCE* equipment has been designed for installation with a minimum of alterations to your vehicle. The installation process is similar to that *of a cellular* phone. However, there may be small cuts into the carpet and a few screws may be driven into the floor of the car. Wires will be hidden in such places as wheel wells or headliners. The computer and antennas will be permanently installed. All boles will be plugged with weatherproof epoxy.

By signing the Agreement for Participation in *ADVANCE, you ape* that *ADVANCE will* not have to compensate you in any way for the costs of these cosmetic alterations to your vehicle.

ADVANCE LIABILITY POLICY

You are responsible for the cost of repairing damages *to the ADVANCE* quipment because of

- negligence or intentional action of a registered driver. such as spilliig fluids on equipment, intentionally hitting the quipmen& etc.:

- damages *to ADVANCE* equipment due to negligence or intentional action (including vehicle accidents) of unregistered driver who has been given permission to drive the vehicle by a registered driver: and

- lost memory card.

You are not responsible for the cost of repairing damages to the *ADVANCE* equipment because of

- Acts of God (flooding, lightning. etc.);

- theft of the entire vehicle

- equipment being stolen as part of a vehicle break-in and

– normal wear and tear on the *ADVANCE* equipment .

The maximum value of damages to the *ADVANCE* equipment that can be charged to the participant/registered driver is S750 as stated in the *ADVANCE* Driver Participation Agreement The value of a lost memory card will be S50

Unregistered drivers are not subject to S750 cap, and may be liable for full cost of equipment (estimated at 56.000). Unregistered drivers are drivers who have not signed the *participation Agreement* and not submitted his/her driver's license number to *ADVANCE* for Secretary of State checking and processing.

LEASED VEHICLES

If your vehicle is leased, we strongly recommend that you tell your **leasing** company that this quipment is being installed into your vehicle. Because of the cost of equipment removal and reinstallation. only those leased vehicle5 tbat have 1½ to 2 years left on the lease have been considered for this test At this time. It does not appear mat leasing costs will increase because of the *ADVANCE* equipment being installed into your vehicle.

If you need to turn in your lesed vehicle for any reason prior to the scheduled end of the lease.. you **must** give the Project Office at least two weeks notice so mat the unit may be removed. If your car is repossessed (or you

GENERAL INFORMATION ABOUT *ADVANCE*

believe it is going to be repossessed); you must call the Project Office with the name of the repossessing agency and the date of repossession as soon as you know it.

AUTO LOANS

If there is a lien on your vehicle and it is repossessed, or you believe it is going to be repossessed. you must call the Project office with the, name of the repossessing agency and the date of repossession as soon as you know it.

INSURANCE

Most insurance companies rely on historical information to determine rates and premiums for their customers. *Since ADVANCE is one* of the first projects to use in-vehicle navigation devices, there isn't any historical information available. The insurance companies are not considered likely to raise premiums charged *to ADVANCE-equipped cars.* However, all insurance companies are different, and the only way for you to determine your company's policy on *ADVANCE* is to check with your insurance agent.

TERM

Unless otherwise determined by the *ADVANCE* Project Manager **or** the Participant, the equipment installed in your vehicle will remain there until the end of the test period, approximately June 1. 1997. The quipment remains the property of *ADVANCE* If or when the equipment is removed from the car-for any reason-it must be remined to *ADVANCE. This is necessay to allow the ADVANCE* Research Team to collect important data from the unit.

AAA-CHICAGO MOTOR CLUB MEMBERSHIP BENEFITS

Non-commercial participants selected for *ADVANCE* receive a prepaid membership in the AAA-Chicago Motor Club (or renewal of their membership if you already are a member). You arc entitled to all of AAA-CMC's membership benefits, including free Emergency Road Service, personalized trip planning. fee-free American Express Travelers Cheques and arrest bond protection. Your *ADVANCE* Information Kit includes the AAA-CMC Membership Handbook. which you should review carefully to learn all of the club's benefits.

Pay particular attention to the Emergency Road Service guidelines. outlined on pp. 0-0 Note that the club does not service licensed common carriers and certain other vehicles, even if they are official participants in the *ADVANCE project.* On the other hand your ADVANCE card entitles you to nationwide Emergency Road Service on any car you are driving.

Questions about AAA-CMC benefits can be directed to the club's Member Assistance Center at 800/AAA-HELP

IMPORTANT PHONE NUMBERS

ADVANCE HELP CENTER: 800/OOO-OO00 (FAX: 708/000-0000)

AAA-CHICAGO MOTOR CLUB EMERGENCY ROAD SERVICE: 8OO/AAA-HELP

ADVANCE PROJECT OFFICE: 708/705-4800 (FAX: 70544303)

MOTOROLA AUTHORIZED SERVICE CENTER: 708/000.0000 (FAX: 0004000)

ADVANCE

ADVANCE DRIVER PARTICIPATION AGREEMENT

1. SAFE DRIVING

You have the responsibility to operate the vehicle safely and in the same manner you would operate any vehicle.

2. INSTALLATION

ADVANCE will not be liable for minor cosmetic alterations to the vehicle occurring on installation or removal of the equipment.

3. TERM

ADVANCE is *lending* this equipment to you until no later than _________, 19___. This equipment is more fully defined in Appendix "A" which is attached to this agreement.

4. NOTIFICATION

If a lawsuit or any claim is made against you which is also related to the *ADVANCE* equipment, you must provide the *ADVANCE* office with copies of all related documents.

5. INSPECTION

ADVANCE may inspect the vehicle and equipment at a mutually agreeable time and at the project service center for the purpose of evaluating, repairing, and upgrading *ADVANCE* equipment.

6. DAMAGES

Beyond normal wear and tear, you are responsible for damage to the equipment caused by your intentional action or negligence or that of your passengers or guests. You are also responsible for lost memory cards. If equipment is damaged through the action set forth above, you agree to pay *ADVANCE* up to a maximum of $750 for *ADVANCE* equipment listed in Appendix "A" and $50 for each lost memory card.

If it is determined by *ADVANCE* that the installed equipment caused damage to your vehicle, *ADVANCE* will either repair the damage or provide you with the fair market value of the vehicle, whichever is less. You agree to accept such compensation as liquidated damages for any damage caused by the installed equipment.

7. INSURANCE

Your automobile insurance policy must provide liability coverage of at least $100,000 bodily injury for each person and $300,000 per accident. You or your insurance company can not cancel or reduce coverage without providing 30 days written notice to *ADVANCE.*

8. TERMINATION

Either party may terminate this Agreement for any reason by giving written notice to the other party. Termination will become effective when *ADVANCE* has removed the equipment from your vehicle. On termination, you must bring the vehicle in to an *ADVANCE* service center for removal of the equipment.

9. PRIVACY

Your operation of the *ADVANCE* equipment and your driving patterns when using this equipment will be recorded for analysis and evaluation of *ADVANCE* and for related scientific purposes. *ADVANCE* will take precautions to maintain the confidentiality of information collected for this experiment.

You and your passengers, however, are presumed to have reasonable expectations of privacy for personal identifying information. Therefore, disclosure to third parties will only occur with your consent or by court order.

10. JURISDICTION

This Agreement shall be construed in accordance with the laws of Illinois and jurisdiction shall be in Cook County.

11. INFORMED CONSENT

By signing below you are stating that:

- you have sufficient information to give this informed consent to participate;
- you are assuming any risk associated with your participation in project;
- you assume liability caused by minors (under 18 years of age) and unauthorized users of the *ADVANCE* equipment; and
- you have received and reviewed the *ADVANCE* Driver Manual Packet.

AUTHORIZATIONS

Participating Driver

Print First and Last Names — Signature

Illinois Driver's License Number ____-______-____ — Birth Date (Month, Day, Year) __-__-19__ — Date

Other Registered Drivers (Must sign this form to be authorized to participate in ADVANCE vehicle.)

Print First and Last Names — Signature

Illinois Driver's License Number ____-______-____ — Birth Date (Month, Day, Year) __-__-19__ — Date

Print First and Last Names — Signature

Illinois Driver's License Number ____-______-____ — Birth Date (Month, Day, Year) __-__-19__ — Date

Print First and Last Names — Signature

Illinois Driver's License Number ____-______-____ — Birth Date (Month, Day, Year) __-__-19__ — Date

Attachment II. Targeted Deployment Driver Participation Agreement

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PARTICIPATION AGREEMENT

This Agreement. dated ________________ , is between *ADVANCE* and ____ (DRIVER(S)). *ADVANCE* is lending certain equipment (described below) to DRIVER in exchange for DRIVER'S full cooperation with the project test. To achieve this goal, the parties agree to the following conditions:

1. **TITLE:** *ADVANCE* and DRIVER agree that *ADVANCE* is lending DRIVER a specially-equipped vehicle (see Exhibit A) for the purpose of testing and evaluating certain on-board route guidance equipment and methods by measuring DRIVER'S use of the vehicle and its equipment and gathering data from DRIVERS through questionnaires and focus groups. Title of the vehicle and the equipment shall remain with its respective owners. DRIVERS shall at all times properly use and maintain the vehicle and equipment (hereinafter together referred to as "equipment"), At DRIVER'S expense, *ADVANCE* shall have the right to repossess the equipment, and according to law, to enter DRIVER'S premises at reasonable times to inspect or remove equipment.

2. **AUTHORIZED DRIVERS:** Due to insurance limitations, only you and your spouse are authorized to use the equipment. No other family member, friend or guest shall be permitted to operate the vehicle or equipment. During the testing, DRIVERS certify that their health status does not interfere with their ability to operate the equipment.

3. **TERM:** *ADVANCE* is lending equipment to you no longer than 30 days from the date the equipment is received. The equipment shall be returned in the same condition it was received, normal wear and tear excepted. Either party, however, may terminate this Agreement for any reason. Upon termination, the equipment shall be returned to ADVANCE by noon of the next business day. Driver is still liable under this agreement until all equipment is properly returned to *ADVANCE*.

4. **DAMAGES:** *ADVANCE* has obtained an automobile insurance policy to cover potential accidents involving you and your spouse. If the accident involving you is covered by the ADVANCE insurance policy, you agree to pat the $500 deductible. If the accident or a cost associated with an accident are not covered by the policy, you and your insurance carrier will be liable for the damages. *ADVANCE* and its agents are not responsible for any loss or damage occasioned by you or your passengers. You are also responsible for all fines and penalties occasioned by your driving behavior (e.g. parking tickets). A $100.00 replacement fee will be charged for each lost memory card. Within 24 hours of an accident, theft or conversion of any equipment, you shall file a written police report and notify the *ADVANCE* office. DRIVER shall furnish *ADVANCE* with every notice or legal document received in every claim arising with respect to the operation of this equipment. DRIVER shall call *ADVANCE* at 708-705-4800 to report a stolen or damaged vehicle.

5. **YOUR PERSONAL INSURANCE:** Your personal insurance policy shall carry $100,000 bodily injury coverage for each person and $300,000 coverage per accident and cover you and all authorized DRIVERs when using *ADVANCE* vehicles. You or your insurance carrier can not cancel or reduce coverage while you are participating in the testing.

6. **PRIVACY:** You understand that interaction with and operation of the *ADVANCE* system will be recorded. *ADVANCE* partners will take precautions to keep the information collected from this evaluation confidential. Such information will only be used for the analysis and evaluation of *ADVANCE* for related purposes. Under Illinois law, governments are required to disclose to the public certain information. You and your passengers, however, are presumed by our government partners to have reasonable expectations of privacy for personal identifying information. Disclosure of such information will only occur with your consent or by court order.

7. **INFORMED CONSENT:** By signing this Agreement you are stating that you have sufficient information to give this informed consent to participate in this test and you are assuming any risk associated with the testing process. You also assume liability caused by unauthorized users of the *ADVANCE* vehicle and equipment, unless the vehicle is stolen, reported to the police, and you are not negligent. *ADVANCE* shall not be liable for any failure in performing any provision hereof due to damaged equipment, government restriction, or any cause beyond *ADVANCE*'s control. In no event shall *ADVANCE* be liable for any loss of profits, other consequential damages or inconvenience due to any loss of profits, other consequential damages or inconvenience due to any theft, damage, loss, delay or equipment failure.

8. **LIMITATION OF USE:** Use of this vehicle shall be limited to the Chicagoland area (Cook, DuPage, Will, Lake, Kendall, Kane, Boone & Will counties), south east Wisconsin, and north west Indiana. Travel outside this region is prohibited unless written approval is obtained.

9. **INDEPENDENCE OF DRIVERS:** In no event shall DRIVERS be considered employees of *ADVANCE* or its members. Drivers agree that they will not hold themselves out as, or claim to be agents or employees of *ADVANCE*, its sponsors or members, and will not make any claim, demand or application to or for any right or privilege applicable to an agent or employee of *ADVANCE* or its sponsors or members, including but not limited to the following: workmen's compensation and occupational diseases coverage, unemployment compensation benefits, social security coverage or retirement membership or credit.

10. **JURISDICTION:** This Agreement shall be construed in accordance with the laws of the State of Illinois.

The following two DRIVERS are authorized *ADVANCE* users:

____________________	____________________
Signature	Signature
____________________	____________________
Print name	Print name

Attachment III. Preliminary Screening Form

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ADVANCE

PRELIMINARY SCREENING APPLICATION

ADVANCE, an initiative between government and private institutions, will test technologies designed to help drivers save travel time, avoid congestion and reduce air pollution.

We're looking for volunteers willing to have a sophisticated navigation computer, communications transceiver and satellite antenna Installed in thelr cars for two years.Thls equipment will suggest effident travel routes considering congestion and road conditions In the communities listed at right.Ascreen In front of the dashboard will direct to each turn along your route. We must recruit at least 3,000 drivers to test this system.

If you are interested In testing the ADVANCEunit in your car for up to two years, and if the "screening statements" below all are true, complete this questionnaire (please print or type) and ... Manager., ADVANCE, 120 W. Center Court Schaumburg, IL 60195.

ArlingtonHeights	Hoffman Estates	Palatine
Barrington	Inverness	Park Ridge
Barrington Hills	Itasca	Prospect Heights
Bensenville	Kildeer	Rivenwoods
Buffalo Grove	Lake Zurich	Rolling Meadows
Chicago (NW side)	Lincolnshire	Rosalie
Deerfield	Long Grove	Rosemont
Deer Park	Medinah	Schaumburg
Des Plaines	Morton Grove	Schiller Park
Elk Grove Village	Mount Prospect	SouthBarrington
Glenview	Niles	Streamwood
Hanover Park	Norridge	Wheeling
Harwood Heights	Northbrook	Wood Dale

SCREENING STATEMENTS

1. I live in one of the communities listed above .... ☐ True ☐ False
2. I am 25 years old or older .... ☐ True ☐ False
3. My household driving record is "clean" (no DUI's, reckless driving, suspensions) .... ☐ True ☐ False
4. The vehicle in which I would like to install *ADVANCE*...
   ...is not a convertible .... ☐ True ☐ False
   ...is not likely to be replaced within two years .... ☐ True ☐ False
   ...was manufactured in 1986 or after .... ☐ True ☐ False
5. My vehicle is provided with at least 100/300 insurance coverage .... ☐ True ☐ False

PERSONAL INFORMATION

Mr. Mrs. Ms. ______________________ ________
Circle One — Print First and Last Names — Today's Date

______________________ ______________________
HOME Street Address/Apt. or Suite — City

IL 6____ ___ ___-____ ___ ___-____
State — ZIP — Daytime Area Code and Phone Number — Evening Area Code and Phone Number

IMPORTANT NOTES

1. If this application shows that you meet the minimum criteria for the program, we will send you a longer questionnaire, in which you will be asked to provide more detailed information about your household, your cars and your driving patterns.
2. Your driving record (and those of other drivers in your household) will be reviewed prior to your acceptance into the *AD*[illegible]
3. Installation of the *ADVANCE* unit in your car requires minor modifications in the passenger compartment and trunk, similar to installation of a cellular telephone.
4. *ADVANCE* is an experimental program and thus we must select drivers based on how well they meet research criteria. For this reason, units are not assigned on a first [illegible]
5. To support research needs, we will record and analyze travel patterns, demographics and attitudes of participating drivers. While every effort is being made to ensure the privacy of participants, *ADVANCE* is not able to guarantee absolute privacy.
6. Prior to the installation of the *ADVANCE* unit in the car, drivers will be asked to sign the *ADVANCE* Driver [illegible]ticipation Agreement.

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Attachment IV. Full Screening (Application) Form

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Dear *ADVANCE* applicant,

ADVANCE is a field test of a computer and communications system designed to give drivers current traffic information and to help them select routes to avoid congestion. This experiment is being conducted in the northwest part of Chicago and the northwest suburbs under the sponsorship of the Federal Highway Administration, the Illinois Department of Transportation, the Illinois Universities Transportation Research Consortium, Motorola, and the American Automobile Association.

ADVANCE is inviting several thousand drivers living in the test area - described on the last page - to use this traffic information and navigation system in their own cars. Drivers will be selected from those applicants who make daily use of their cars in the test area, have good driving records, and are willing to keep the navigation systems in their cars for the entire test period. This form will help us find those drivers. Please *NOTE that:*

- Because *ADVANCE* is an experiment, we must select a representative group of drivers to evaluate this new technology: not all applicants can be chosen to participate.
- Navigation and communication systems will be installed in each selected vehicle and removed at the end of the test. These systems will include a phone-book size computer in the trunk, a video display near the dashboard, and two outside antennas.
- Some vehicle types are not compatible with the *ADVANCE* system and must be excluded.
- Drivers are expected to participate in *ADVANCE* through 1997. However, participants whose driving safety falls below *ADVANCE* standards, who move from the test area, or who sell or otherwise dispose of their motor vehicles, must surrender their navigation systems.
- The equipment remains the property of the *ADVANCE* project, and will be - maintained, and removed at the expense and discretion of the project managers.
- The *ADVANCE* on-board system will automatically record vehicle usage in the test area, and participating drivers will be surveyed periodically to assess their experience with *ADVANCE.* This information will be encoded to protect driver privacy.

If you are interested in becoming an *ADVANCE* driver, please complete, stamp and return this application. You must answer all questions to be considered for participation. If you have questions about *ADVANCE* or this application, call our recruitment coordinator at (708) 7054800.

Sincerely yours,
Joseph F. Ligas
ADVANCE Project Manager

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HOUSEHOLD INFORMATION (please print)

1. Home address and telephone:

_______ number _______ street _______ apartment

_______ city _______ zip code Phone: ( ) _______ home telephone, nights, weekends

2. Please Drint names and driver's license numbers of all drivers in your household, starting with yourself.

List names exactly as shown on driver's license		Driver's license number
First and middle name or initial	Last name	
(YOU) ______	______	☐☐☐☐☐☐☐☐☐☐☐☐☐☐
______ ______	______	☐☐☐☐☐☐☐☐☐☐☐☐☐☐
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______ ______	______	☐☐☐☐☐☐☐☐☐☐☐☐☐☐

3. How did you find out about *ADVANCE?* ☐ newspaper ☐ radio ☐ TV

☐ traffic report ☐ friend or family ☐ AAA Magazine ☐ other_______

VEHICLE INFORMATION AND DRIVING PATTERNS

On the next two pages we ask for information about up to two of your household vehicles which you want to be considered for installation of the *ADVANCE* unit. We also ask for information about the primary and alternate drivers who use each of the two cars. The primary driver of either vehicle is the person who drives that vehicle most often and the alternate driver is the one who drives the vehicle second most frequently. Do not list vehicles if the primary driver is under twenty five years of age, the vehicle is a convertible, has a plastic body, is a two-seat sports car, or is a model year earlier than 1986. These vehicles cannot be included in the *ADVANCE* field test.

FIRST VEHICLE (Please Print)

4. Make ____________ 5. Model ____________ 6. Year _____ 7. Color ________

8. Type: ❑ Sedan ❑ Panel truck ❑ RV ❑ Sport-Utility Vehicle
❑ Wagon ❑ Convertible ❑ Pickup ❑ Van ❑ Other_______

9. Does this vehicle contain CB, amateur, or other mobile radio transmitters? ❑ yes ❑ no
do not check for cellular telephones

10. This vehicle is: ❑ owned ❑ leased until ______ ❑ company car
month year

11. Is this vehicle insured for injury and property liability for at least $100,000/person and $300,000/accident? ❑ yes ❑ no

12. Insurance Company Name: ________________________ 13. Policy number: __________

14. Is this vehicle likely to be replaced in the next two years? ❑ yes ❑ no

15. Vehicle license plate number ______________

Please answer the following questions about the **primary driver** of this vehicle:

16. ❑ Mr ❑ Mrs. ❑ Ms. ❑ Dr. ____________________________
first name last name

17. Year of birth: ___________ 18. Gender: ❑ male ❑ female

19. If the primary driver is employed outside the home and usually reports to work at the same place each day, please indicate the address and phone number of that work site; if this driver starts work at different workplaces on different days, skip to question 20.

______________________________ ______________________
employer name number street

________________ ________________ Phone: ( ) ________________
city zip code

20. For primary drivers whose work sites vary, how many days each week is the workplace first visited located in the test area communities listed on the last page of this application? ______

21. Please answer the following questions about trips of the primary and alternate dirvers on the vehicle	Primary Driver	Alternate Driver
Number of days per week this driver **drives** this vehicle to work		
Typical number of trips per weekday this driver **drives** this vehicle (see note below)		
weekend (Saturday and Sunday) this driver drives this vehicle		
Total miles this driver **drives** in this car during a typical week		

Note: **A trip goes from a single origin to a single destination. For example, a journey from work to a store (1). to a restaurant (2) and then to home (3) is counted as three trips.**

SECOND VEHICLE **(please print)**

22. Make ____________ ***23.*** Model ____________ ***24.*** Year ______ ***25.*** Color ________

26. Type: ❑ Sedan ❑ Panel truck ❑ RV ❑ Sport-Utility Vehicle
❑ Wagon ❑ Convertible ❑ Pickup ❑ Van ❑ Other ________

27. Does this vehicle contain CB, amateur, or other mobile radio transmitters? ❑ yes [] no
do not check for cellular telephones

28. This vehicle is: ❑ owned ❑ leased until ____ , . ____ ❑ company car
n year

29. Is this vehicle insured for injury and property liability for at least $100,000/person and $300,00O/accident? ❑ yes ❑ no

30. Insurance Company Name: ____________________ ***31.*** Policy number: __________

32. Is this vehicle likely to be replaced in the next two years? ❑ yes ❑ no

33. Vehicle license plate number _______________

Please answer the following questions about the **primary driver** of this vehicle:

34. ❑ Mr. ❑ Mrs. ❑ Ms. ❑ Dr. ______________________________
first name **last name**

3.5. Year of birth: ____________ ***36.*** Gender: ❑ male ❑ female

37. If the primary driver is employed outside the home and usually reports to work at the same place each day, please indicate the address and phone number of that <u>work site</u>; if this driver starts work at different workplaces on different days, skip to question 38.

______________________________ ______________________
employer name **number** **street**

______________ ______________ Phone: ( ) __________________
city **zip code**

38. For primary drivers whose work sites vary, how many days each week is the workplace first visited located in the test area communities listed on the last page of this application? ________

39. Please answer the following questions about trips of the primary and alternate drivers of this vehicle.	Primary driver	Alternate driver
Number of days per week this driver **drives** this vehicle to work		
Typical number of trips per weekday this driver **drives** this vehicle **(see note below)**		I
Typical number of trips per weekend (Saturday and Sunday) this driver **drives** this vehicle **(see note below)**		
Total miles this driver **drives** in this car during a typical week		

Notes **A trip goes from a single origin to a single destination. For example. a journey from work to ;l store (1). to a restaurant (2) and then to home (3) is counted as three trips**

DRIVER SAFETY INFORMATION

It is important that *ADVANCE* drivers have and maintain good safety records. For all drivers listed in question 2, please answer the following questions. **Note that *ADVANCE* will verify driver performance using official records.**

40. Do any drivers in your household have an illness which might degrade their driving performance (e.g., seizures, blackouts)? [] yes [] no

41. Do any drivers in your household regularly take medications which might reduce their alertness when driving? [] yes [] no

42. Do any drivers in your household have uncorrected vision or hearing problems which degrade driving skills (e.g., night vision, hearing)? [] yes [] no

43. Have any drivers in your household been convicted of more than three moving traffic violations in the past 3 years? [] yes [] no

44. Have any drivers in your household been found at fault as a driver in a traffic accident with serious injuries or fatalities in the past 3 years? [] yes [] no

45. Have any drivers in your household had their license suspended for any reason in the past 3 years? [] yes [] no

46. Have any drivers in your household ever been convicted of driving under the influence of alcohol or drugs, reckless homicide, or hit-and-run accident? [] yes [] no

I certify that the information I have entered above is correct to the best of my knowledge.

Signature ______________________ Date ____________________

Suburbs and Chicago Zip Codes Included in the *ADVANCE* Test Area

Arlington Heights	Elk Grove Village	Lake Zurich	Northbrook	Schaumburg
Barrington	Glenview	Lincolnshire	Palatine	Schiller Park
Barrington Hills	Hanover Park	Long Grove	Park Ridge	South Barrington
Bensenville	Harwood Heights	Medinah	Prospect Heights	Streamwood
Buffalo Grove	Hoffman Estates	Morton Grove	Riverwoods	Wheeling
Deerfield	Inverness	Mount Prospect	Rolling Meadows	Wood Dale
Deer Park	Itasca	Niles	Roselle	ChicagoZipcodes:
Des Plaines	Kildeer	Norridge	Rosemont	60631, 60634
				60648, 60656

Thank you for your interest in *ADVANCE.* Please fold this form along the dotted line on the last page, tape or staple, affix a 29C stamp and drop it in the mail. We will respond to you about enrollment in the *ADVANCE* program in about six weeks.

Attachment V. Secretary of State Driver Record Screening Criteria

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Secretary of State Driver Record Screening Criteria

The SOS action codes that will be used to reject ADVANCE applicants are shown in the furthest column to the left, "TYPE OF ACTION". The action items on the list are the ones that will disqualify an applicant. Should any of these numbers appear in the "TYPE OF ACTION" column, the applicant is rejected.

01 Mandatory revocation
02 Discretionary revocation
03 Discretionary suspension
04 Safety responsibility suspension
05 Financial responsibility suspension
06 Unsatisfied judgement suspension
07 Parking ticket/warrant suspension
08 Cancellation of license
09 Failure to appear suspension
16 Collision involving fatal injury
17 Statutory summary suspension
18 Vehicle emissions suspension
27 Illinois license surrendered to foreign state
28 Reported deceased
32 Denial of restricted permit
33 Denial of license
34 Extension of revocation
35 Extension of suspension
37 Extension of statutory summary suspension
41 CDL disqualification hearing
57 Statutory summary suspension item
78 Restricted/Occupational driving permit
79 Judicial driving permit
82 Out-of-state conviction (DL and/or CDL sanctions imposed)
91 Conviction of driver under 18 at time of arrest
93 Immediate action conviction - bond forfeiture (no point assigned)
94 Immediate action conviction (no point assigned)
FP Failure to pay court imposed fine
IV RDP invalidated
DQ Disqualification
OS Out-of-service
SC Suspension/conviction (when offense committed in a CMV)

These moving violations need to be counted and used as a criterion for selection:

68 Out-of-state conviction (record history item only)
80 Out-of-state accident
87 Out-of-state conviction (points assigned)
95 Conviction - bond forfeiture (no points assigned)
96 Conviction (no points assigned)
97 Conviction bond forfeiture (points assigned)
98 Conviction - points assigned

For the items listed directly above, the number of violations must be counted and a per year rate must be determined. To determine the per year rate, the column titled “EFFECTIVE DATE OF ACTION” must also be read. If there are three or more occurrences of the 7 moving violations listed above in the last three years, the applicant is rejected. If there is more than one occurrence of the 7 seven moving violations listed above in the last year, the applicant is rejected.

APPENDIX H

PROBES AND DETECTORS: EXPERIENCES GAINED FROM *ADVANCE*

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PROBES AND DETECTORS: EXPERIENCES GAINED FROM ADVANCE

EXECUTIVE SUMMARY

This paper presents some key aspects of probes and detectors that the authors have learned through their participation in the design and evaluation phases of ***ADVANCE***

Some of the early decisions made during ***ADVANCE*** design are revisited. For example one such decision was to use default travel time estimates called static profiles. These estimates would be on CD-ROMS in equipped vehicles and would be replaced by dynamic estimates only when the latter differed substantially from the former. This decision, which was taken originally on the basis of RF capacity constraints, was controversial. However, it is now that this would have been a good idea even if there was no RF capacity constraint. This also implies the great importance of static estimates.

Properties of probe observations that we have learned from analyzing them are also discussed. The quality of probe reports is excellent. Probe reports are not statistically independent. This implies that the simple statistical formulae often used in traffic engineering need to be reexamined because they are based on independence of observations. Another implication is that there is a severe diminishing marginal return in quality with respect to the level of deployment. This implies that not much improvement in quality of estimates will occur as we go from fairly low levels of deployment to much higher levels; in other words a very high level of market penetration is not needed for a probe based system to be effective. Finally, any procedure which uses probe information needs to recognize the inherent stochasticity of such information.

The experience of the authors in attempting to convert detector information into travel time estimates is also covered. It is shown that while detectors are fairly effective under low and moderate congestion, unless the deployment of detectors is increased, detectors are not of much value in high congestion situations. .

A brief comparison of probes and detectors is presented in a conclusion.

PROBES AND DETECTORS: EXPERIENCES GAINED FROM ADVANCE

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1.0 INTRODUCTION

1.1 Abbreviations and Definitions

All terms and acronyms used in this document that are specific to *ADVANCE* are defined in the System Definition Documents #8020.ADV.06, available for examination and downloading from the *ADVANCE* project homepage. (http://ais.its-program.anl.gov/).

1.2 Authors

Contributing authors to this document are:

Ashish Sen, Professor of Urban Planning and Policy and of Mathematics, Statistics and Computer Science at the University of Illinois at Chicago (UIC). He is currently also the Acting Director of the Urban Transportation Center (UTC) and Director of the Statistics and Evaluation Laboratory at UIC. UTC has been involved in the *ADVANCE* project since its inception and Professor Sen was responsible for the design of several components of the traffic related functions (TRF) component of ADVANCE. Professor Sen, along with Professor Soot and Dr. Berka, is conducting an evaluation of all prediction algorithms associated with *ADVANCE*. Professor Sen has been on the UIC faculty for over 25 years and received his doctorate from the University of Toronto.

- **Siim Soot** Associate Professor of Geography and Urban Planning and Policy at the University of Illinois at Chicago. He has been on the university faculty since 1970 and is currently also Acting Associate Director of the Urban Transportation Center. For several decades he has studied the growth of the Chicago area and how this has affected urban travel behavior.

- **Stanislaw Berka,** Ph.D., Post-Doctoral Research Associate at the Urban Transportation Center, the University of Illinois at Chicago. Dr. Berka received his doctorate from UIC. He has been involved in the design and development of several traffic-related-function components of the *ADVANCE* Project, first as a research assistant, and since receiving his Ph.D., as a research associate. His thesis concerns the highway travel-time estimation model applied in *ADVANCE*, and he was responsible for the design and development of the Base Data (BD) subcomponent. He was also responsible for the evaluation of all loop detector data-related subcomponents of *ADVANCE*.

1.3 Intended Audience

When the designers of the TRF component of *ADVANCE* started working on the project, they sought the experience of others who had used probe and/or detector reports for travel time computation and forecasting and found the literature rather sparse. While the *ADVANCE* project has been extremely well documented, some of the decisions taken in the course of designing components of the system and how well the system fared after implementation do not always make their way into formal reports. The purpose of this report is to fill these gaps by revisiting some of these decisions.

This report is intended to be of use to anyone interested in computing or forecasting travel times from probes or from detector reports. It should be of particular value to anyone designing ATIS systems.

1.4 References

Readers might find some of the following reports useful. They go into greater detail about the procedures mentioned in the report. For a more complete list of papers and reports in support of the *ADVANCE* Project, written by Urban Transportation Center faculty and staff, visit the Urban Transportation Center WWW page at http://www.uic.edu/depts/cuppa/utc/ and click on the link marked "*ADVANCE* Working Papers and Technical Reports".

D.E. Boyce, J. Hicks, and A. Sen, (1991a) *In-vehicle Navigation Requirements for Monitoring Link Travel Times in a Dynamic Route Guidance System, ADVANCE* Working Papers Series, Number 1, Urban Transportation Center, University of Illinois, Chicago.

D. E. Boyce, J. Hicks and A. Sen, (1991b) *In-vehicle Navigation Requirements for Monitoring Link Travel Times in a Dynamic Route Guidance System, ADVANCE* Working Papers Series, Number 2, Urban Transportation Center, University of Illinois, Chicago.

D. E. Boyce, J. Hicks and A, Sen, (1991c) *In-vehicle Navigation Requirementsfor Monitoring Link Travel Times in a Dynamic Route Guidance System, Operations Review 8 17-23.*

J.E. Hicks, D.E. Boyce and A. Sen, (1992) *Static Network Equilibrium Models and Analyses of Dynamic Route Guidance Systems,* A Technical Report in Support of the Design Phase of the *ADVANCE* Project, Urban Transportation Center, University of Illinois, Chicago.

J. Li, A. Sen, N. Rouphail and P. Thakuriah, (1992) *Short-term Flow Predictions: A Review of Existing Algorithms, ADVANCE* Working Papers Series, Number 14, Urban Transportation Center, University of Illinois, Chicago.

N. Liu, and A. Sen, (1994) *Dynamic Travel Time Prediction in ADVANCE for Release 1.5 TTP Algorithm Report, ADVANCE* Working Papers Series, Number 34, Urban Transportation Center, University of Illinois, Chicago.

N. Liu and A. Sen (1995), *Dynamic Travel Time Prediction in ADVANCE: Modified Release 1.5 TTP Algorithm Report and Detail Design Document (#8600), ADVANCE* Working Papers Series, Number 46, Urban Transportation Center, University of Illinois, Chicago.

M. Mathes, and A. Sen, (1995) *Static Estimates of Travel Times in ADVANCE: Release 2.0 SPU Algorithm Report and Detail Design Document (#8600), ADVANCE* Working Paper No. 49, Urban Transportation Center, University of Illinois, Chicago.

A. Sen et al, (1991) *Short-Term Forecasting of Link Travel Times: A Preliminary Proposal, ADVANCE* Working Paper No. 7, Urban Transportation Center, University of Illinois, Chicago.

A. Sen et al, (1996) *ADVANCE* Evaluation: Base Data and Static Profile, Urban Transportation Center, University of Illinois, Chicago.

S. Soot and H. Condie, (1996) *ADVANCE Evaluation: Quality of Probe Reports,* Urban Transportation Center, University of Illinois, Chicago.

Urban Transportation Center, University of Illinois, Chicago (1995), *Evaluation Test Plan: Base Data and Static Profile*

2.0 PURPOSE

The main purpose of this white paper is to detail experience gained from the thinking that surrounded the design of *ADVANCE* and also our understanding of *ADVANCE* and of ATIS systems in general from the targeted deployment of *ADVANCE*. This paper is concerned with the effectiveness of probe and detector reports in this context.

The purpose of both probes and detectors is to gather information about prevailing traffic conditions on a link in order to provide route guidance to vehicles which have the necessary on-board equipment. The key information required by vehicles is link travel time. Therefore, this report will be mainly confined to the problem of estimating link travel times from probe and detector reports.

Both probes and detectors can be useful in detecting incidents, and incidents clearly constitute a primary determinant of travel time, especially as they alter the travel time from its usual level. However, the issue of incident detection and the effects of incidents on travel times is a subject complex enough to merit a dedicated report. For this reason, incidents are not covered in this report. Instead, this paper concentrates on generic travel time estimation from detectors and probes, particularly under recurrent congestion.

3.0 FINDINGS

3.1 Background

The effectiveness of a dynamic route guidance system depends on being able to gather up-to-the-minute information about conditions on the links in the transportation network it serves. Other than personal anecdotal reports, there are basically two possible sources of such information: vehicles recording and reporting their own travel times or other behavior as they travel and some form of out-of-vehicle surveillance. In the *ADVANCE* project both sources were used. Equipped vehicles called probes measured their own travel times on each link they traversed. They also measured congested time (the time spent traveling under 2 meters per second) and congested distance (the distance covered while traveling under 10 meters per second) for each link. These were reported back to the TIC via radio-communications channels. About a tenth of the links in the *ADVANCE* area, on both expressways and signalized arterials, had loop detectors which gave both volumes and occupancy data over 5-minute intervals. However, since all route guidance was based on travel times, volume and occupancy information needed to be converted into travel time estimates. Since both types of information gathering systems (in-vehicle and out-of-vehicle surveillance) were used in the *ADVANCE* system, our experience with these systems should be of use to future ITS designs, particularly those which attempt to estimate travel times.

These same sources of information can be, and indeed were used for updating static estimates (also called static profiles) of the usual travel time on a link in the absence of incidents. However, for static estimation an additional source of information is available. The Chicago Area Transportation Study (CATS) conducts periodic surveys of travel behavior, compiling extensive datasets which are available to researchers. These data can be input to a 4-step urban transportation planning (UTP) procedure to yield estimates of link volumes and link travel times. The advantage of this source is that no *ADVANCE*-generated data are needed for this. Therefore, estimates from such a model (called the Network Flow Model) were used in *ADVANCE* to construct static estimates before enough data had been collected by probes to construct probe-based static estimates.

Travel time estimates obtained in these different ways were used by the on-board navigation computers (called MNA's) in the equipped vehicles to compute desirable routes, as was outlined in the description of *ADVANCE* given earlier. This white paper deals with probe and detector information, the methods used to generate travel time estimates from them, and their overall performance. All these issues have been considered in the various *ADVANCE*-related reports mentioned previously.

While developing procedures for constructing such estimates we had to address a number of questions, take decisions, and confront difficulties that did not fit conveniently into the above-mentioned reports. Examples range from fundamental questions as what is precisely meant by link travel time to more practical issues about sample sizes, deployment levels and data storage. It is more than likely that future developers of probe-based, detector-based or hybrid systems will confront the same questions. This report is aimed at addressing some of them.

During the time we were working on the development of *ADVANCE* very little was available by way of field observations. Still, we had to address the issues in the *ADVANCE* development process, sometimes having to make assumptions. The data collected after deployment gave us the opportunity to revisit some of them. In this report we will describe how we addressed these issues during the design stage, what we learned after we had data, and how we might address these issues if they were to arise in the future.

Some critical issues are still not completely resolved and will have to await further examination. For example, a critical issue that has not been finally resolved is the problem of estimating travel times at a signalized intersection using detector data. This is particularly difficult during times of heavy congestion which also lasts a long time.

3.2 Level of Probe Deployment

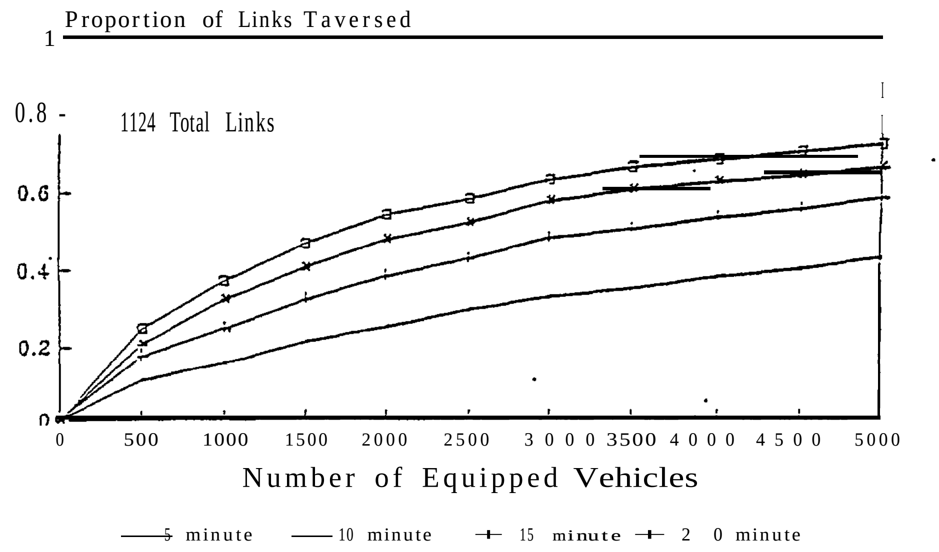
The decision to make *ADVANCE* a largely probe-based system had been made before any significant participation the authors of this report. At that time, the level of deployment had not been chosen.

Budgetary issues played a key role, as did two working papers by Boyce, Hicks and Sen (1991a, 1991 b) later published as a paper (Boyce, Hicks and Sen, 1991 c). Using a matrix of trips between every origin and destination (O-D matrix) constructed by the Chicago Area Transportation Study (CATS), a network equilibrium procedure was used, along with some factoring assumptions, to estimate the number of links which would have at least one trip per 5, 10, 15 and 20 minute interval in the peak period. Some results from the report are shown in Figure 3.1.

It became clear that coverage as defined in the last paragraph rapidly increases with the number of equipped vehicles and then flattens out. Thus while reasonable link coverage could occur at modest deployment levels, complete coverage of all links (one vehicle per link per 15 minutes, say) would be unduly costly. Based on such information a deployment level of 5000 vehicles was chosen initially.

Because at that time there was virtually no information available on link flows, this method appears to be an appropriate first step. Some of the assumptions made, though, could bear reexamination.

Link Coverage of North Shore Network
Arterial Links with One Lane



Link Coverage of North Shore Network
Arterial Links with Two Lanes

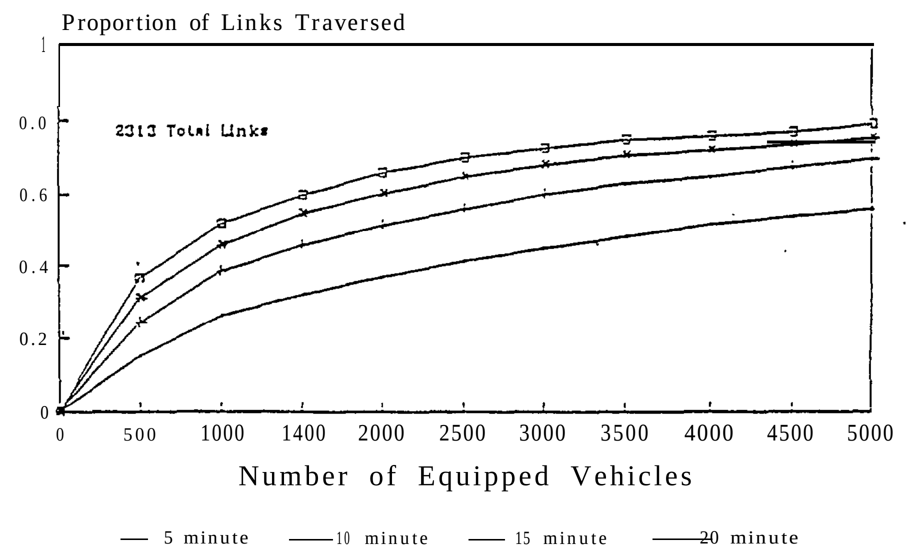


Figure 3.1: Coverage at Several Probe Deployment Levels

One critical question is whether one probe per 15 minute interval is a reasonable criterion. At one level it is not. Since probe reported travel times have enormous variances (as discussed in Section 3.7. l), a single observation does not provide much information. On the other hand:

*A minimum of 1 probe per 15 minutes could have several links getting well over the minimum (see UTC (1995) *Base Data and Static Profile Evaluation Test Plan,* p. 7-9).

*The links that get very few or no probes are less traveled links and might not play a major role in route guidance. Moreover, travel times on lightly traveled links rarely vary enough due to recurrent congestion to warrant surveillance.

*As we shall see in Section [Image] , the variance of mean travel times for several probes on heavily traveled links declines very slowly with the number of probes and, consequently, trying to get very accurate travel time estimates simply by raising sample sizes would be prohibitively expensive.

> We need to add that we realized this fact after data were available from probe deployments. Moreover, the functions linking mean probe travel times to sample sizes are still link-specific.

During the design stage, time did not permit a thorough investigation of these aspects of the problem. Nor did we know enough about probe based systems to have been able to conduct such an investigation. In fact, a detailed investigation still has not occurred. If we were to take a guess based on the targeted deployment, we would say that 3000 to 5000 probes would have yielded a reasonably well-functioning system.

3.3 Use of Static Profiles

Broadcasts of link travel times and their forecasts are received by the MNA when the probe vehicle's ignition is turned on. Few users, though, would be willing to wait very long after that point to receive guidance. RF capacity was not considered to be sufficient to transmit all the necessary information for over 10,000 links in the *ADVANCE* area in an acceptably short period of time. Therefore, the decision was taken to have default estimates of travel times on a CD-ROM in the MNA. Whenever an actual travel time was known to be significantly different from the static estimate, a correction was sent to the vehicle over RF.

While this approach was taken in order to circumvent the practical limitation of RF capacity, it turns out that it was a very good approach and should have been taken even if there was more than enough RF capacity. This is true because of the large variance of estimates of travel times from probe reports. Dynamic estimates, whether they are forecasts or estimates of current conditions, are based on very few observations for every link. Moreover, the correlations between such observations make the variance of such estimates even larger (see Section 3.7.1). On the other hand, static estimates are based on data for several days. Consequently, the static estimates are constructed from many more observations and correlation between observations is also less of a problem.

It is preferable to use the much more reliable static estimates unless one is reasonably certain that road conditions are quite different from normal - which would be the case if dynamic forecasts were to differ from static forecasts by a substantial amount. The *ADVANCE* design called for a statistical test of the hypothesis that expected travel times for a given interval on a particular day would be different from expected travel time for the interval under 'normal' conditions. Broadcast would only occur if the hypothesis were to be rejected.

The effect of this overall approach was examined by means of a simulation in a dissertation by Thakuriah (1994) summarized in a paper (Thakuriah and Sen, forthcoming). While the dissertation examined a large number of options and is a bit too complicated to summarize here, the best procedure turns out to be very similar to the one adopted by the *ADVANCE* project. The approach of having default static estimates which would be overwritten by dynamic estimates under exceptional conditions remained the best approach even at deployment levels approaching 100 percent.

Thakuriah's dissertation also introduced the concept of an ideal travel time that would be incurred by an omniscient driver - a driver who is able to choose his/her route on the basis of the exact time he/she would personally incur on each link. Approaches similar to the one taken in *ADVANCE* yielded route travel times for route-guidance equipped vehicles which were very close to those incurred by the fictional omniscient driver.

The authors of this report did not suspect that this situation would be the case before the Thakuriah study. Since under the *ADVANCE* scheme dynamic travel time estimates would be provided only if their difference from the corresponding static estimate exceeded a certain threshold, we had been concerned that a route where the dynamic estimate for a single link exceeds the threshold would be discarded by the MNA in favor of a route where several links had dynamic travel time estimates just under the threshold. In spite of this possibility, the Thakuriah simulations satisfactorily established that the approach taken in *ADVANCE,* albeit for different reasons, is statistically the most desirable.

3.4 Representation of Travel Times

The decision to represent travel times as step functions was taken very early in the design stage. By step function representation, we mean that the day would be divided into several intervals and a single number would yield the travel time during any of the intervals; i.e., an estimate of travel time would be the same for any time within the same time interval.

For static estimates a weekday was to be divided into 48 intervals, while weekends and holidays would be divided into 24 intervals. The number was chosen after negotiations between those involved with estimation and those involved with the data bases on the MNA CD-ROM. Clearly, the interests of the latter group consisted of keeping this number down since each link had a different static profile. Final design allows for each link to have a different number of intervals up to a maximum value.

During the targeted deployment, a number of links were carefully analyzed and several methods (including the use of regression trees) were used to divide the 1 PM to 7 PM weekday interval into a number of smaller intervals for which most data were available. The analysis seems to indicate that 12 intervals were more than enough for the l-7 PM period. Since the evening rush hour ends before 7 PM, it would appear that 24 intervals would be more than enough for the entire PM period and one could conjecture that 48 intervals would be enough to represent the whole day. While we examined only a few links and a larger number of links might require more intervals, we would still conjecture that 48 was an adequate number.

There were some difficulties reported in representing travel time as a step function in static profiles. Link travel times (or, more precisely, expectations of link travel times which are the quantities we estimate) as a function of time of day are essentially continuous. Thus, the static estimates near the edges of each interval become too approximate (See Figure 3.2). A better method might have been to represent link travel times as piecewise linear functions (see Figure 3.3). Storage requirements would not be too adversely affected, since all we would need would be the value of the function at the boundary points between the intervals and link travel-time values for points within the interval can be found by interpolation. Since a piecewise linear function might fit better, fewer intervals might be needed overall. More complex functions (e.g., splines) could also be used, but it is not clear to us how that would affect storage and speed of computations.

The 5-minute interval for dynamic forecasting was probably chosen on the basis of TIC and COM processing times. While five minutes might appear to be very short from a statistical point of view since for a given link very few probes reports would be gathered during five minutes, sample size of probes is actually not a problem. This observation is valid because estimates need to be made for a 5-minute interval; there is no requirement that they be based only on observations from the appropriate interval. Observations from adjacent intervals could be used and indeed were used.

Thus, the choice of the length of the intervals for dynamic estimates does not depend much on the number or quality of probe reports. Rather, the critical issues are timeliness of the information broadcast, processing times at the TIC and RF capacity.

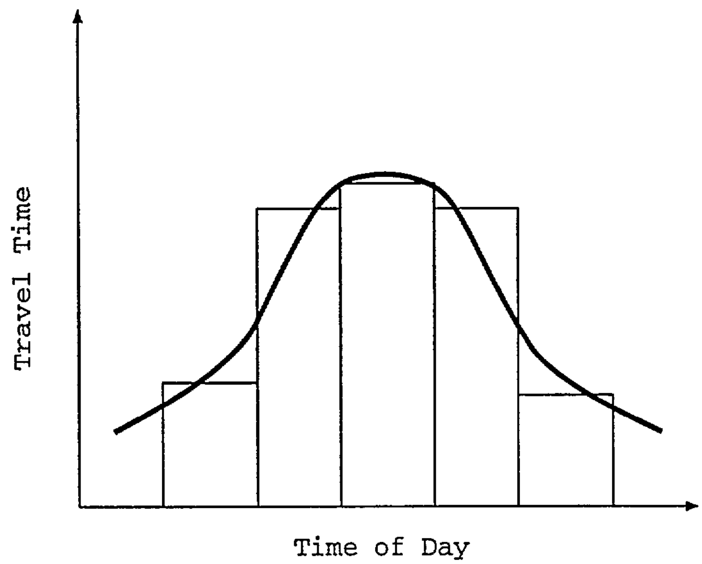


Figure 3.2: Travel-Time Representation: Step Function.

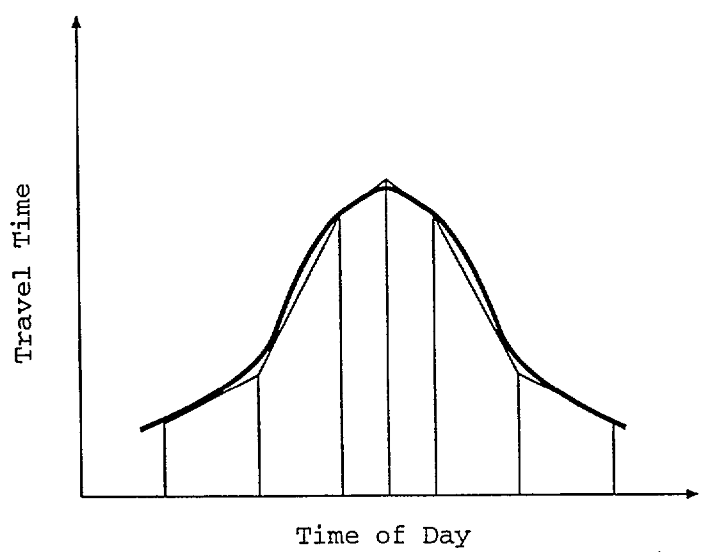


Figure 3.3: Travel-Time Representation: Piecewise Linear Function.

3.5 One-Link-at-a-Time Analysis

It is perhaps worth discussing the early decision to base most estimation on a one-link-at-a-time basis (see J. Li et al (1992) *Short-term Flow Predictions: A Review of Existing Algorithms).* An alternative would have been to base forecasts on volumes on upstream links. At that time no realistic options were available as we describe below (except for initial static estimates for which a network equilibrium model was used). However, the issue might be worth discussing because future developers of similar systems might prefer to choose other options.

There were several reasons why we had no realistic options. One possibility we examined was to use a dynamic traffic assignment model. Apart from the fact that none were available at that time, getting origin-destination (OD) volumes presented a problem. While it has been suggested in the literature that OD volumes could be estimated on the basis of link volumes, we did not have the ability to estimate link volumes on most links. Simulation models such as NETSIM were also not considered practical since they were not fast enough to be used on line, given the size of the *ADVANCE* area. Moreover, getting the inputs for such models is a major undertaking.

While we constructed most forecasts on a one-link-at-a-time basis, our experience has given us some insights as to whether some other procedure, had we been able to use it, would have been better. The discussion of this section is focused mainly on these.

3.5.1 Static Estimates

As mentioned above, a network equilibrium model (the NFM) was used to estimate initial travel times, which were then revised using actual probe travel times. As described in detail in A. Sen et al (1996), *ADVANCE Evaluation: Base Data and Static Profile,* the estimates obtained from the model were not very accurate. While this conclusion could be due to deficiencies in the specific model constructed, there are a number of reasons why such models cannot yield very precise travel times on a congested system of arterials with signalized links.

One reason is that typically both volumes and travel times on links vary. Consider the volume travel-time relationship shown in Figure 3.4. We have shown three volume levels A, B and C under congested conditions and the corresponding travel times a, b and c. It is easily seen that the average of the three travel times do not correspond to the average of the three volumes (which is B).

Another reason is that volumes on each route are assigned to all links on the route uniformly. However, capacities of upstream links can act as filters, reducing the volumes on downstream links. See Figure 3.5. As a consequence, under recurrent congestion downstream links do not approach capacity even though route volumes are high. This fact is not represented within assignment models.

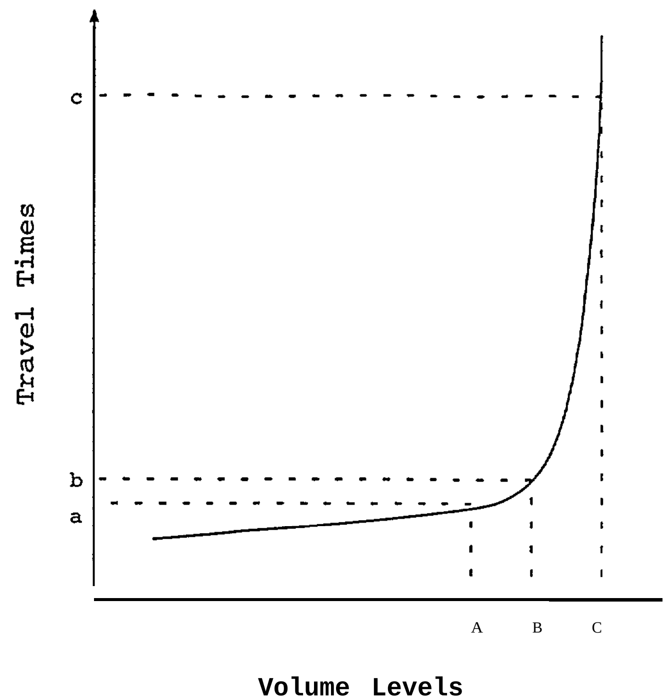


Figure 3.4: Volume-Travel Time Relationship 1.

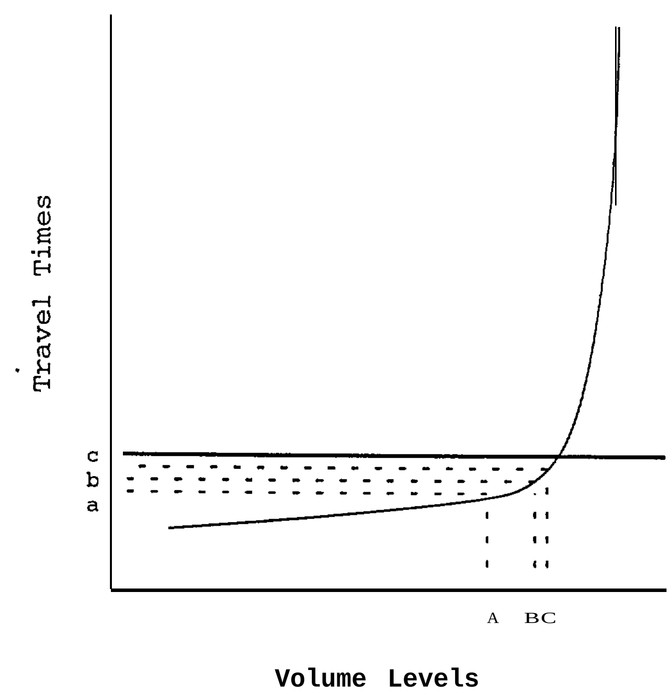


Figure 3.5: Volume-Travel Time Relationship 2.

After the static estimates were revised on the basis of probe observations, the resulting estimates of travel time were quite accurate. We are convinced that at the present time probes constitute the best method for obtaining static estimates, whether such estimates are used in *ADVANCE-type* systems or in simpler systems providing only autonomous guidance.

3.5.2 Dynamic Estimates

Since the most useful link travel time provided to a vehicle is that which the vehicle would encounter when it traverses a link, the most useful dynamic travel time estimates are forecasts. One could make the claim that the only useful estimates are forecasts.

Since we chose a one-link-at-a-time approach, forecasts of travel times were based on past travel times on the same link only. While several methods were tried, the ultimate model used was an ARIMA model, a time series model forecasting model of the kind frequently encountered in business applications (see N. Liu and A. Sen *(1995), Dynamic Travel Time Prediction in ADVANCE: Modified Release 1.5 TTP Algorithm Report and Detail Design Document (#8600)).* Under recurrent congestion, any forecast of travel times based on past travel times on the same link would depend on unusual levels of congestion persisting for fairly long periods and the duration of the persistence having enough of a pattern so it can be forecast.

In the dynamic travel time forecasting procedure used, we constructed forecasts 5, l0 and 15 minutes into the future. It is unlikely that unusually high levels of recurrent congestion persist for over 15 minutes. Whether the forecasts made by *ADVANCE* are reasonably good within the 15-minute time period has not yet been thoroughly examined.

We would conjecture that examining a single link at a time would not yield forecasts as good as those we might have been able to get had we examined upstream links. Upstream volumes are good predictors of downstream volumes, particularly if we have reasonable estimates of percentages of turning movements. We conjecture that for short-term forecasting a promising approach would be to base estimates of volumes on a link on upstream volumes and then to estimate link travel times on the basis of volumes.

We could not do this forecasting in *ADVANCE* because the vast majority of links were not detectorized. Moreover, even the detectors which did exist were hard-coded to yield volumes and occupancies over 5-minute intervals, information much too coarse for the purpose mentioned above.

Estimating travel times from volumes does not appear to be too difficult if the cycle lengths and green splits of traffic signals are known. Our analysis shows that the oft quoted formula: travel time = cruise time + stopped delay holds reasonably well. Stopped delay can be estimated fairly closely using traffic engineering methods.

3.6 Quality of Probe Reports

During the summer of 1995 approximately a dozen probe vehicles were driven on weekdays in north suburban Chicago. During this time almost 60,000 miles were driven in urban traffic conditions to produce over 55,000 link reports. These reports provide information on three critical elements of travel: travel time, congested time and congested distance. This information was computed in the vehicle's on-board Mobile Navigation Assistant (MNA) and it was recorded in two different ways, directly onto a memory card in the vehicle and via radio frequency at files tabulated at the project office's Traffic Information Center (TIC) located in Schaumburg, Illinois.

In assessing the quality of the data two type of tests were performed. The first test was performed by observers riding in the probe vehicles and recording travel time, congested time and congested distance. The second test was performed by comparing the probe data for the three measures against logical limits.

In the first case observers riding in the probe vehicles recorded the times vehicles passed the end of each link. This information was converted to produce link travel times which were then compared with link travel-time data recorded by the MNA. Over 85% of these comparisons were within five seconds and well over 90% were within ten seconds.

We took these results to be a very positive reflection on the quality of probe data. There are several reasons why human observation would not yield exactly the same numbers as the MNA. A key one is the nature of the GPS. While a very accurate GPS was used in *ADVANCE,* even these are within 10 meters only about 90% of the time. This occurs because satellite information is deliberately scrambled because of law. Therfore, the human observers did not know precisely where a link began and ended for a given link traversal. If the vehicle was moving slowly between the times the MNA thought the link had ended and the observer thought it had ended, fairly large differences could occur. In addition there is always the possibility of human error.

Therefore, in spite of the fact that MNA's appear to do about as well as any equipment with a similar purpose would, a user of probe reports must tolerate the fact that probe observations are random variables with a small but not negligible variance. This provides further evidence to statements made for different reasons, elsewhere in this report, that methods for using probe data must take into account their inherent stochasticity.

Human observers were also used to record congested distances and congested times but neither of these measurements could be performed with precision. Both required close monitoring of the vehicle's speedometer in order to note when the probe vehicle speed dropped below the critical speed. The accuracy of an analog speedometer at low speeds is uncertain and particularly with the distance measurement it was not possible to have the observer replicate precisely the information recorded by the MNA. The tests showed that when there was no congested time or no congested distance then the MNA confirmed this and when either condition was observed then the MNA reports a positive time or distance measure. Based on our tests we concluded that the MNA was properly measuring and recording both congested distance and congested time.

The second step in assessing the quality of probe reports consisted of comparing probe reports against logical limits to the variable being measured. These included excessive speeds, congested distances that exceeded link lengths, and unrealistically short congested distances when congested times were recorded. Each of these three checks uncovered approximately 100 records among the over 50,000 probe reports examined. In some cases these traced to a faulty MNA in a particular vehicle.

When all of these suspect reports were combined they still represented far less than 0.5% of all probe reports. We were very satisfied that the MNA's were producing data which was about as high quality as possible.

Overall, the results indicate that the MNA's in particular and probe reports in general are a rich and accurate source of data on road conditions. However, for a variety of reasons their essential stochasticity needs to be borne in mind when constructing estimates. For further information on quality of probe reports, we direct readers to the report , *ADVANCE Evaluation: Quality of Probe Reports, S. Soot and H. Condie,* (1995).

3.7 Additional Properties of Probe Travel Times

In this section we discuss some properties of travel-time observations provided by probes. Most of these properties are somewhat obvious, but since we had not anticipated them until we encountered them, they deserve mention. In particular, we shall address the issues of the lack of statistical independence among probe observations and the effect of traffic signals. The former is critical since most statistical formulae given in textbooks are derived under an assumption of independence. Dependence therefore invalidates all of them.

3.7.1 Dependence Among Probe Reports: Same Link

Probe-reported travel'times for different vehicles on the same link can be dependent. There are several possible reasons for this. As an example of the first reason, consider a signalized arterial link with moderate congestion (with no cycle failures). A vehicle which arrives at the intersection just after the signal turns red will have a very similar travel time to that of another vehicle which also arrives just after the light turns red. Similarly, a vehicle which moves through the intersection without having to stop or slow down will encounter travel times similar to another vehicle that faced similar conditions. These are the two extreme cases; similarities of travel times will occur in the in-between cases as well (e.g., vehicles arriving halfway into the red phase). Travel time similarities lead to correlation between travel times.

The correlations between probe reports can be empirically verified. While we do not go into all the details as to how they were estimated, Figures 3.6, 3.7 and 3.8 display some correlations. Figure 3.6 shows correlations between pairs of probe-reported travel times with the horizontal axis measuring the headway or the difference in exit times of the two vehicles. That is, each point on the plot is of the form (x,y) where y is the correlations between travel times of a pair of probes and x is the difference in exit times. A pattern is easily visible.

Further clarification occurs if, instead of travel times, we use congested times and plot them against vehicle headway. As we have stated previously, congested times can be viewed as a surrogate for stopped delay. Figure 3.7 shows the plot. As expected, we see a smooth periodic function, the periodicity reflecting traffic signal cycles. Consider the difference between link travel times and congested time, which may be viewed as an approximation of cruise time on the link. The relevant plot is shown in Figure 3.8. It demonstrates a weak level of correlation decreasing with headway. There are also low-level correlations which are periodic, possibly showing effects of stopped delays on cruise time variations.

These correlations have a profound effect on the statistical analysis of data. One effect of this dependence is on the formalae connecting standard errors of estimates and sample size. While we do not present details of the changes in formalae necessitated by dependence nor the method of estimation, we present the effect on standard errors of means of probe reports in Figure 3.9. Estimates of standard errors are on the vertical axis, while the horizontal axis shows number of probes on the link over a five-minute interval. The standard errors of the mean of probe reports do not go to zero as would happen under independence. There is a minimum value below which standard errors never fall, no matter how large the number of probes becomes. While this minimum value is link specific, the general shape of the relationship between standard errors and sample size appears is similar for all moderately or heavily congested signalized links.

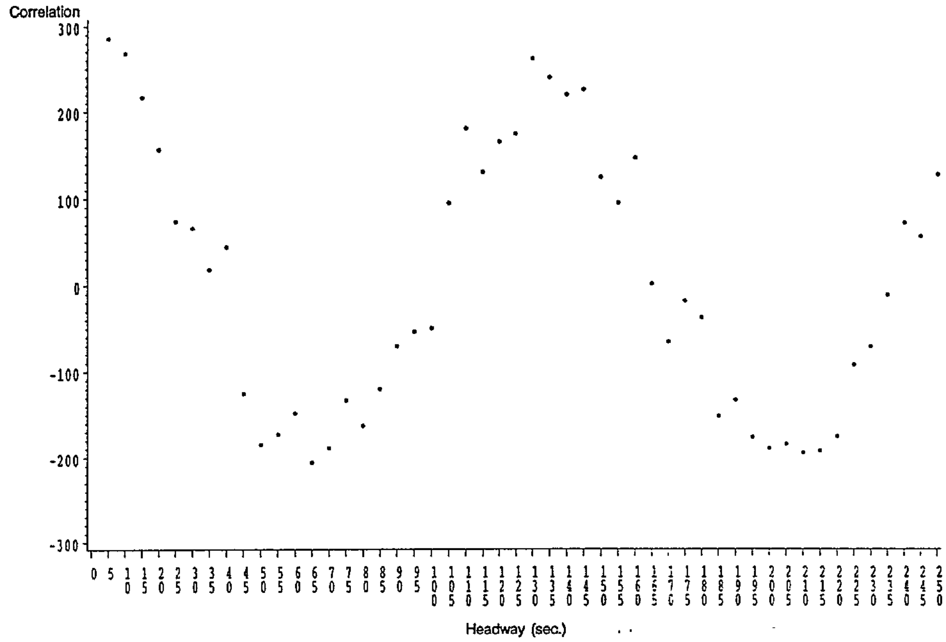


Figure 3.6: Correlation between Probe-Reported Travel Time vs. Vehicle Headway

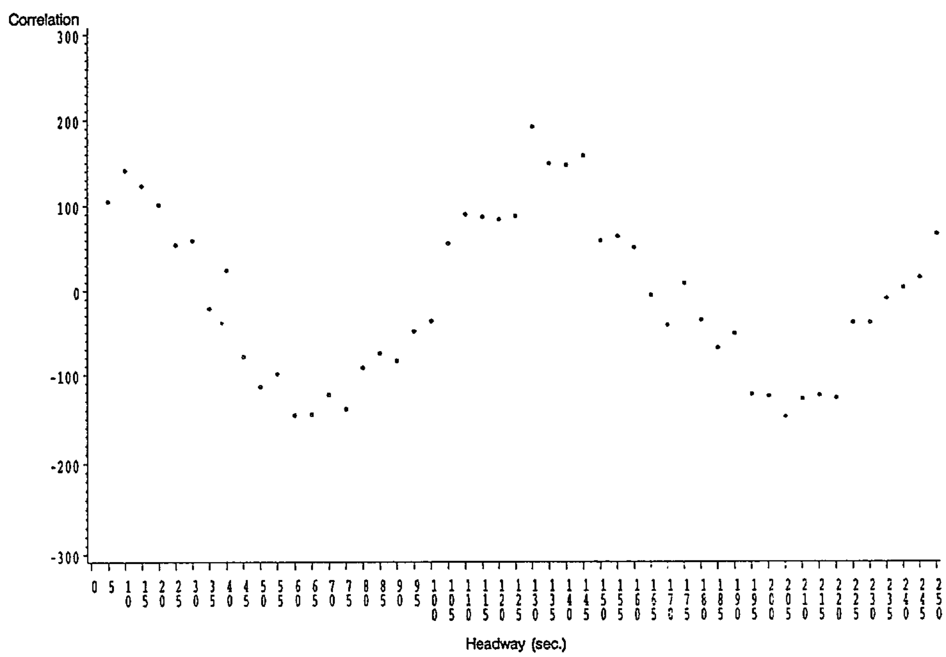


Figure 3.7: Correlation between Probe-Reported Congested Time vs. Vehicle Headway

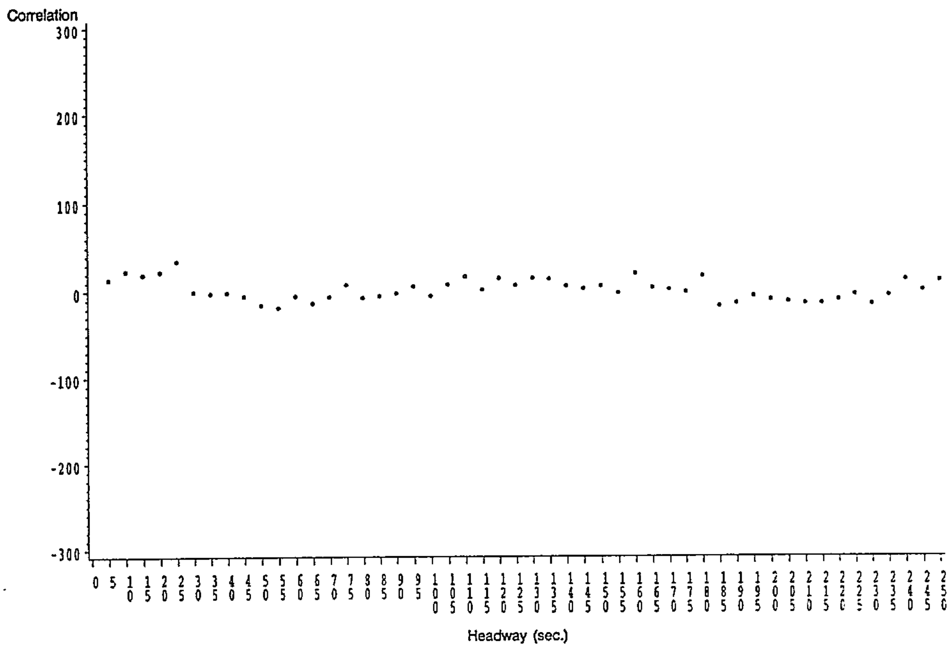


Figure 3.8: Correlation between Probe-Reported Travel Time - Congested Time vs. Vehicle Headway

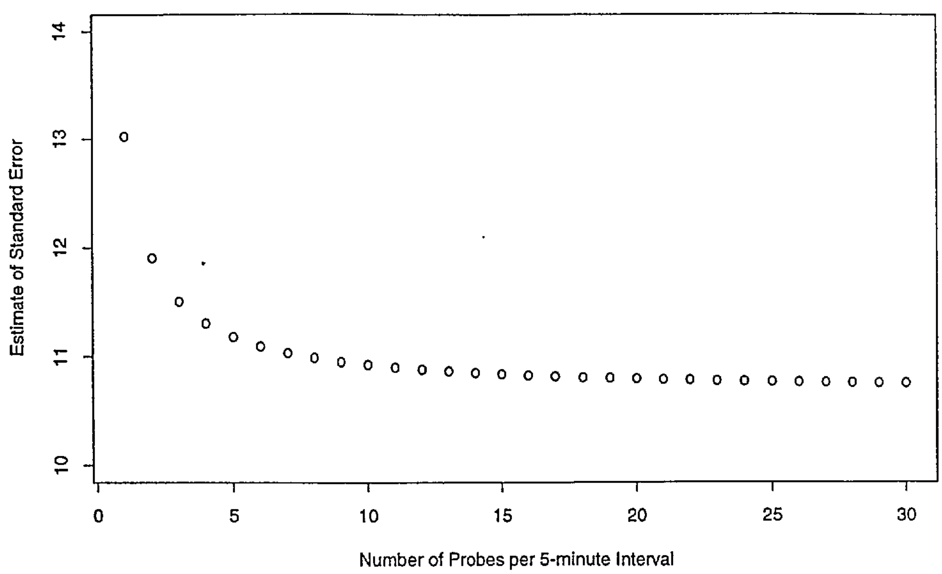


Figure 3.9: Standard Error vs. Number of Probes per 5-minute Interval

The plot also shows that for moderately or highly congested signalized links the most improvement in the quality of the estimate (i.e., the most reduction of standard errors) occurs for small sample sizes while for large sample sizes the improvements flatten out. This situation has two implications:

*A relatively small number of probes yields about as good estimates as a much larger number. This has major implications for market penetration issues. Even relatively low market penetrations would yield estimates almost as good as 100 per cent penetration.

*The variance of estimates never approaches zero. Thus, exact link travel times will never be known; procedures in dealing with link travel-time estimates must take this stochasticity into account.

Notice that for relatively uncongested links, link travel-time estimates are of little importance if only recurrent congestion is considered.

The above discussion was for mean probe travel times - the means being computed for relatively short periods of time; e.g., 5 minutes. One might be able to reduce the variance by taking other covariates into account. Since traffic signals have as much effect as they do, one method of reducing the variance of estimates is to take them explicitly into account. This procedure would require precise knowledge of when each phase begins on every traffic light in the system as well as knowledge of when each probe vehicle exits each link. This information was not available to us in *ADVANCE,* and getting it would not have been easy. Apart from any other reason it would have required that each clock involved be synchronized perfectly. While we do not know exactly how difficult this would be, we would conjecture that it would have been quite expensive. Estimation of link travel times might have been significantly enhanced had we been able to get this information. Work is currently underway at the National Institute of Statistical Sciences to obtain cycle lengths and the start of green times for each traffic signal phase from probe data alone. The success of this work would improve travel time estimation in future probe-based studies. However, we did not have benefit of this work during the *ADVANCE* project.

We were aware that link travel times are correlated, and indeed the forecasting methods used in the TT component of *ADVANCE* were based on the existence of correlations. Thus, while we need to reduce the unpleasant effects of such correlations, the correlations can be beneficial in helping us construct forecasts.

3.7.2 Dependence Among Probe Reports: Adjacent Links

There are several possible causes for dependence in the travel times reported by a probe on contiguous links. Clearly one (perhaps minor) cause is the fact we would be dealing with the same car and driver. More important causes are platoon formation and progression.

If a vehicle is a part of large platoon, it will frequently remain so for several links, carrying its surrounding congestion (or perhaps even the lack of it) along with it for several links. Since congestion levels are related to travel times, this situation would tend to lead to travel times on the same car for different links being correlated.

On well-progressed links, a vehicle stopped at a red light at one intersection might not have to stop at a traffic signal for several succeeding intersections so long as it is traveling at prevailing speeds and is not turning. Thus what a vehicle encounters on one link would be related to what it encounters on succeeding links. Another outcome of this relationship is that travel times on contiguous links become correlated.

While we have no doubt that probe reports on contiguous links are correlated, we do not know much about the nature of the correlations. We cannot, for instance, even assert that they would be positive; indeed, we would expect the correlations to vary between link pairs and even over time of day.

Their effect on route guidance, however, can be profound. If, for example, link travel times were uncorrelated, then route travel times under recurrent congestion would not vary too much: If a car encounters unusually high travel times on one link, it would frequently encounter lower-than-usual travel times on others links. In this case, there would be little need for route guidance except under non-recurrent conditions.

Under correlated conditions, the situation becomes different. To return to one of the causes given above, the congestion surrounding a vehicle on one link might travel with the vehicle over several links. Then the higher-than-normal travel time on one link would then be followed by the same situation on succeeding links.

As in the case of the single link case, correlations between travel times on separate links can be of use in the forecasting process. However, we do not as yet have sufficient understanding of them to actually use them.

3.8 Detectors: General Properties

Detectors can be of many types, including pneumatic sensors, inductive loop, magnetic, magnetometers, ultrasonic sensors, microwave sensors, infrared sensors, and video cameras. Inductive loop detectors are the most widely used of these and are the only ones deployed in the study area. These units are buried underground, within the road surface, and detect vehicles by counting changes in the inductance of the detector caused by the passage of inductive materials (cars) over the detector.

Loop detectors can be used singly: i.e., a detector covering each lane would be more or less isolated with no other detector covering the same link near it. Such detectors supply two types of information:

*Volume, which is the number of vehicles passing over the detector over some given time period (e.g., 1 minute, 5 minutes).

*Occupancy, which is the proportion of time a vehicle occupies the space above the detector.

Double loop detectors consist of two detectors placed close together on the same link. These configurations are capable of estimating speeds of vehicles passing over them although sometimes even widely-spaced single detectors can be used to get average speeds.

At any given time, loop detector occupancy can be viewed as being in one of two states: vehicle and no-vehicle. As such, potentially very detailed information can be obtained from detectors. However, detectors on arterials are typically installed to aid with the timing of traffic lights and, consequently, are hard coded to yield only volumes and occupancies. This encoding is certainly true for both arterials and expressways in the study area.

Consequently, our discussion of detectors will be largely confined to these two measurements and to their use in the estimation of travel times. Only about 10 percent of links in the study area were detectorized and even for detectorized links contiguous links were seldom detectorized. Therefore, much of our experience was with making link travel-time estimates one link at a time; i.e., we had virtually no experience with estimating link travel times using upstream or down-stream detectors.

It is well known that as a matter of overall trend, link travel times increase with volume. One would expect that volumes as measured by detectors would be good predictors of link travel times. This assumption is indeed true up to a point as Figure 3.10 illustrates.

As mentioned earlier, travel times encountered by cars depend on several factors, not just on volumes. For example, when a vehicle enters a link the signal stage has a noticeable effect on the vehicle’s travel times. Under moderate congestion, some vehicles will go through the intersection during green without stopping, while other vehicles might have to stop for the entire red phase and the travel times for such vehicles might not even be much affected by volume. The best we can hope for would be that volume observations obtained by detectors would allow us to estimate mean travel times. That detector estimates perform reasonably well in this capacity is seen from Figure 3.10 since probe-experienced travel times cluster symmetrically around the line shown. It is also seen that, as should be expected, the points are not too close to the line, illustrating that factors other than link volumes also affect travel times.

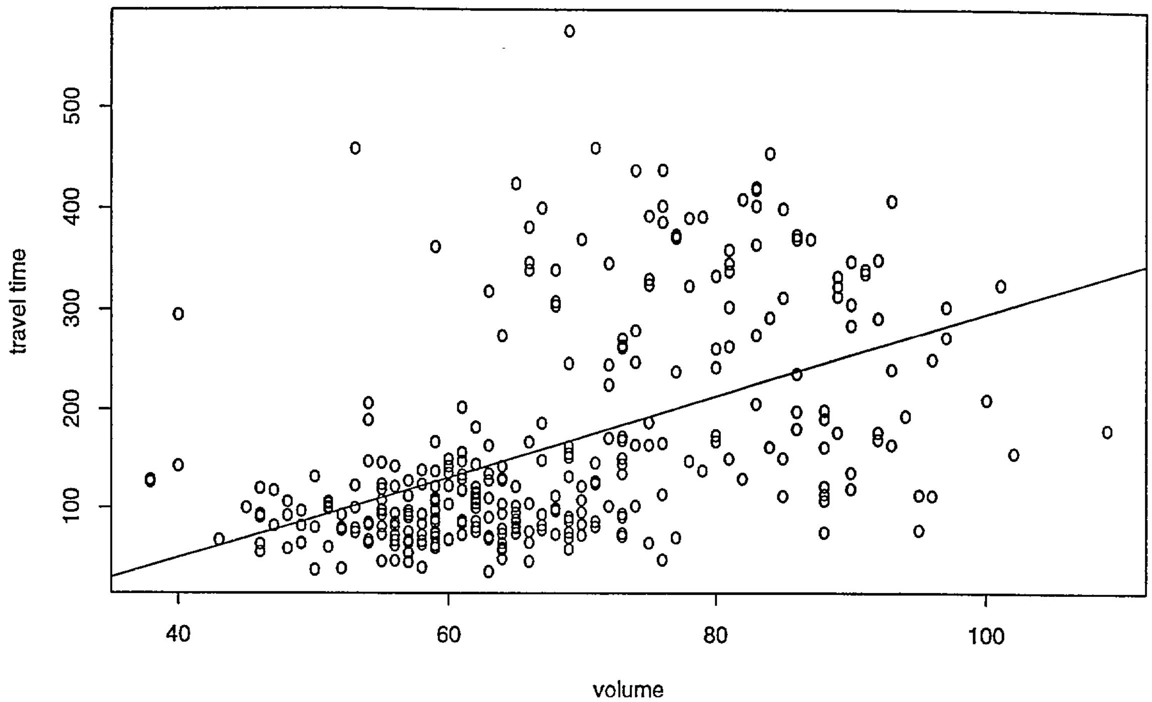


Figure 3.10: Detector Volume and Link Travel Time Relationship: Link 7

Under conditions of high congestion, detector volumes are essentially measurements of the capacity of the link. Detectors are usually placed close to the exiting intersection and measure the volumes exiting the link. Higher volumes on the link, while they affect travel times, would not be measured by the detector. Thus, very high congestion levels, which might be of the greatest interest for route guidance, would be those that would not be noticed by detectors.

As mentioned above, detectors also provide occupancy rates. When speeds are slow and, consequently, gaps between consecutive vehicles are small, occupancy rates are high. Thus one might expect occupancy rates to provide estimates of travel times. Figure 3.11 shows a plot of mean probe travel time versus travel time estimated using a formula developed for *ADVANCE*. Again we see that while there are clearly other factors which affect the travel times of individual vehicles, occupancy rates provide a reasonably good means for estimating mean travel times under low and moderate congestion.

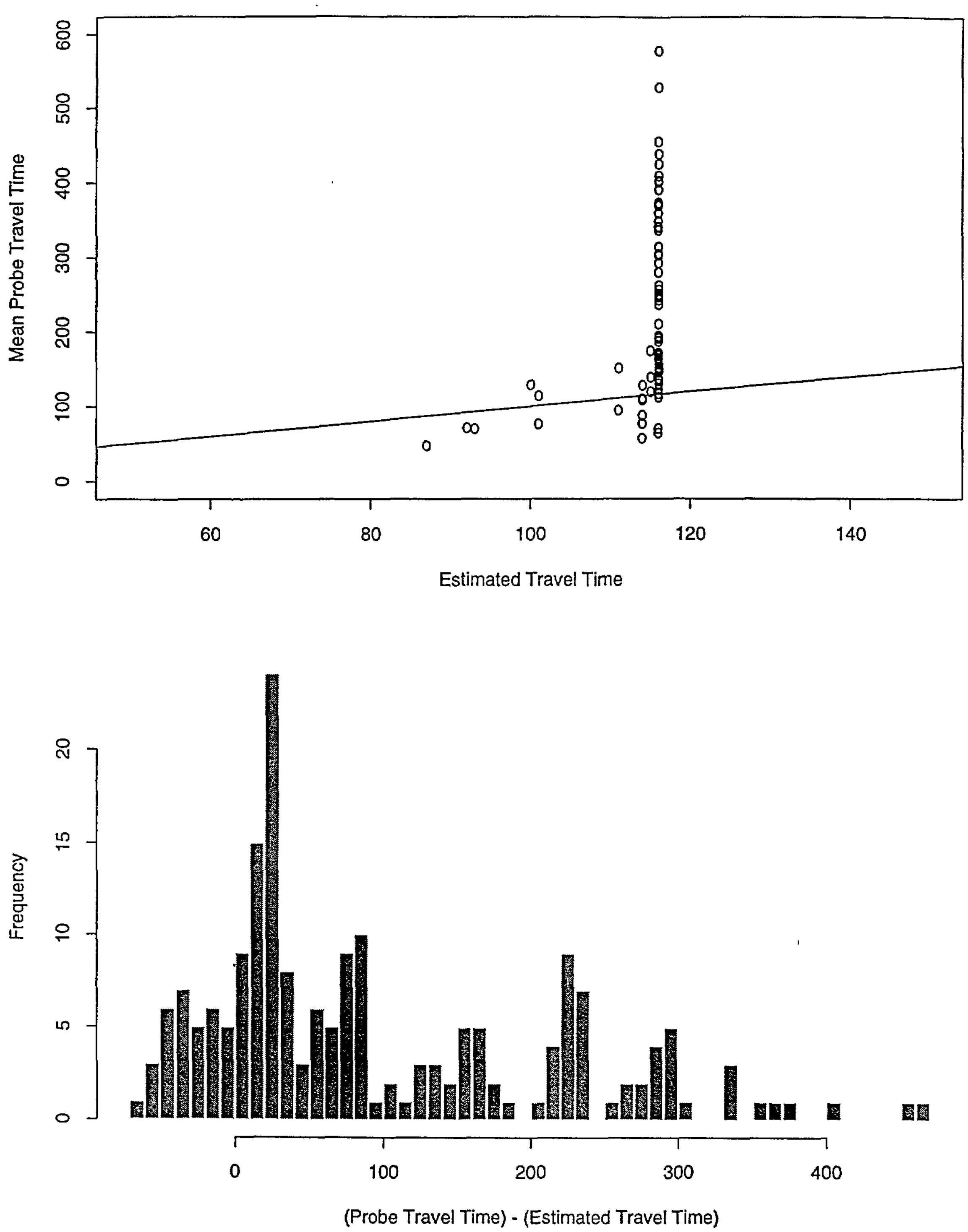


Figure 3.11: Estimated Travel Time: Link 7 (Peak Period, Detector Data Only.)

However, under heavy congestion, occupancy rates are not of much use. When the queue at the traffic signal becomes so long that it extends beyond the detector, there is no way that the detector would be able to measure distinctions in queue length or travel times. This shortcoming is illustrated by the vertical band of points on the right of the plot.

Thus, both volume and occupancy measurements do a reasonably good job of estimating mean travel times under moderate congestion, although other factors affect the travel times of individual vehicles and these factors are impossible to capture using detectors. However, when volumes are high, particularly under saturated conditions, detector measurements are of little value in estimating travel times.

There might be ways of remedying the situation. Detectors can be placed at the entry end of a link. Then the volume measurements obtained from them might be more useful than measurements from detectors close the exit of the link in estimating travel times even under high volume situations [although it is unclear how effective occupancy measurements would be]. But such detectors might not be of great value for the control of traffic signals, the primary current use of loop detectors.

Even more preferable might be to estimate link volumes on all links, which would provide us with entering volumes for every link, since this information would be the sum of exit volumes on all links upstream to it. Moreover, detectorizing all links might yield benefits for short term forecasting as mentioned at the end of Section 3.5.2 - although the cost could be very high.

4.0 CONCLUSIONS AND SUGGESTIONS

We have covered a large number of probe-related decisions taken during the ADVANCE project and have commented on their outcome. Surprisingly, while we did not have much experience with probes at the time these decisions were taken, the decisions proved to be excellent in the light of subsequent information. The quality of reports provided by probes was generally very accurate.

Some suggestions can still be made, and many have been mentioned already. A principal suggestion is that attempts be made to get as much information as possible about the timing and phasing of traffic signals. Another suggestion would be to use the data gathered for further research.

A key finding was that it is necessary to be careful in using statistical methods on probe-vehicle travel-time reports because they are not independent, a condition assumed in developing most standard statistical formulae. For some computations the effect of this non-independence of reports can be great. Also, because of the large variances involved in the link travel times of vehicles, their stochastic nature must be borne in mind at all times. This assertion implies that some standard traffic engineering methods, like standard statistical methods might not always be of value when using probe-based information.

In general probe vehicles provide a very valuable source of information which has been exploited well in the *ADVANCE* design.

4.1 A Comparison of Probes and Detectors

While we have had the opportunity to examine probe reports extensively, our experience with detectors is more limited, largely because few links in the ADVANCE area were detectorized and rarely did we even have detectors on contiguous links - a configuration which would have been of considerable potential value.

It is the consensus of the various research teams examining these data that at present probe-vehicle information is more valuable than that provided by detectors. However, detector information can be improved. As previously mentioned, detectors have been used primarily for the purpose of controlling traffic signals. For detectors to be of significant value for travel time estimation they need to be designed and deployed with this alternate use in mind.

Considerably more detailed information than aggregate 5-minute readings would be required - perhaps even the ‘raw data’ recorded for each instance when a vehicle passes over a detector. Moreover, detectors need to be deployed more extensively, on almost every link. This option could become very costly, particularly if we consider the amount of information that would have to be transported. While large-scale probe deployment is also costly, individual motorists buying in-vehicle units would handle much of the expense, while costs of deploying detectors would probably be largely a public expenditure.

Since we have no experience with such a system, we acknowledge its potential but are unable to comment further. However, we can say that probes do work well, they are a proven technology, and with further research are a very effective way of monitoring road conditions and providing ATIS and ATMS.

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APPENDIX I

INSTITUTIONAL ISSUES

Charles Sikaras
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Paul Dowel1
Motorola

Syd Bowcott
De Leuw, Cather and Company

INSTITUTIONAL ISSUES

EXECUTIVE SUMMARY

This paper emphasizes specific institutional issues confronted in the performance of the *ADVANCE* operational test. The' major institutional issues for *ADVANCE* related to the progression of an Intelligent Transportation System (ITS) technological development effort from concept to reality.

The July 9, 1991 IVHS Agreement for the *ADVANCE* Project established the mutually agreeable terms to engage in this cooperative demonstration to design, develop, implement and evaluate *ADVANCE* While this Agreement served as the guiding contractual document, several complexities arose in the implementation of the Agreement. These. complexities resulted from the Agreement being general in nature, its relationship to specific agreements that were subsequently executed with each Party, leadership changes that occurred among the *ADVANCE* Parties after execution of the Agreement, the delicate role that was placed on the Project Manager, and the evolving changes that occurred with the Agreement during the life of the Project. The challenges encountered in *ADVANCE* also placed an emphasis on the continuous involvement of legal and financial staffs from each of the Parties and the need to define procurement processes before executing innovative agreements.

Each of the *ADVANCE* Parties was concerned about their potential financial liability resulting from operation of the *ADVANCE* fleet. In an attempt to safeguard the financial interests of the *ADVANCE* Parties, the Project Office secured insurance according to specified criteria. The insurance policy needed to cover multiple drivers including employees of the *ADVANCE* Parties, other participants, guests/visitors, and motorists from the general public. A small number of firms (less than five) proposed insurance premium quotes that varied significantly because of the lack of familiarity with an *ADVANCE*-type system.

The minimal actual insurance losses that were experienced during the *ADVANCE* Targeted Deployment were partially due to precautions taken by the Project in assigning the *ADVANCE* vehicles. A relationship was also established with the Illinois Secretary of State's Office to electronically check the driving records of all potential *ADVANCE* drivers licensed in Illinois. The insurance issues for a full-scale ITS deployment would have placed more emphasis on the participant's insurance and hence would have been more complex.

The *ADVANCE* Project Office instituted comprehensive procedures for fleet operation issues. These procedures included log sheets for each vehicle that listed the next service date for vehicle maintenance, a daily log for each vehicle that included beginning and ending mileage figures, a table containing all important information for each vehicle, and daily early morning meetings during the

Targeted Deployment Phase to address vehicle mechanical difficulties and/or MNA system operating malfunctions encountered in the previous day of testing.

Some of the major lessons learned in *ADVANCE* included developing and executing comprehensive driver participation agreements, providing sufficient information regarding project specifics to each driver, providing adequate assistance for malfunctioning vehicles or navigational equipment, and establishing adequate procedures to resolve procurement/audit issues with private sector participants. In addition, the Project learned that the roles of its Parties needed to match assigned responsibilities and respective talents.

At times, the institutional issues encountered in *ADVANCE* caused minor delays in the Project because they caused uncertainty in completing administrative responsibilities according to schedule. However, despite these obstacles, the Parties made the commitment to work together to satisfactorily complete the goals and objectives established for the Project. Equally important, the institutional issues identified and resolved in *ADVANCE* will serve as valuable lessons for future ITS projects.

INSTITUTIONAL ISSUES

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1.0 INTRODUCTION

Many studies of institutional issues emphasize the complexities involved in the design, development and performance of Intelligent Transportation System (ITS) projects. Several of the institutional issues associated with the *ADVANCE* (Advanced Driver and Vehicle Advisory Navigation Concept) Project have been addressed in other Achievements and Perspectives Evaluation Papers (i.e. Public-Private Partnerships) and the March 1994 IVHS Institutional Issues Case Study on *ADVANCE* performed by the Volpe National Transportation Systems Center for the Federal Highway Administration (FHWA). This current paper will emphasize more specific institutional issues confronted in the performance of the *ADVANCE* operational test.

1.1 Acronyms and Definitions

Acronyms and definitions are contained in the *ADVANCE* System Definition Document #8020.ADV. To aid in reading this report, several of the more common terms are defined below.

AAA-CMC - American Automobile Association - Chicago Motor Club.

ANL - Argonne National Laboratory.

FHWA - Federal Highway Administration. One of the founding Parties. FHWA is responsible for the overall evaluation of the *ADVANCE* Project.

GSA - General Services Administration.

IDOT - Illinois Department of Transportation. One of the founding Parties. IDOT is responsible for providing project management for ADVANCE and for operating the TIC.

ITS - Intelligent Transportation Systems.

IUTRC - Illinois Universities Transportation Research Consortium. One of the founding Parties. IUTRC is a non-profit corporation owned by Northwestern University, the University of Illinois at Chicago, the University of Illinois at Urbana-Champaign, and the Illinois Institute of Technology.

IVHS - Intelligent Vehicle Highway Systems.

MNA - Mobile Navigation Assistant. An in-vehicle system designed and built by Motorola that determines vehicle position, performs route planning based on current traffic information, and provides dynamic route guidance information to the driver.

Motorola - One of the founding Parties. Motorola provided the in-vehicle system as well as the RF communications systems.

RFP - Request for Proposal.

SBU - Strategic Business Unit.

TIC - Traffic Information Center. The TIC consisted of the hardware, software, and operations personnel in a centralized facility. It communicates to and receives information from the probes and external systems.

1.2 Authors

The authors of this report, involved in the development of the communications subsystem for *ADVANCE* are as follows:

Charles Sikaras

Mr. Sikaras has been employed in the transportation industry for approximately twenty years after earning a Bachelor of Science degree in Transportation Management from the University of Illinois at Chicago in 1976. Mr. Sikaras has been employed as an ITS Program Specialist for IDOT since 1992. Previously, he served as Transportation Director for the Chicagoland Chamber of Commerce from 1983 to 1992. Mr. Sikaras began his transportation career with IDOT as Fiscal Manager for the Division of Public Transportation from 1976 to 1980 and also served as Program Manager for IDOT's Bureau of Railroads from 1980 to 1983.

Paul Dowel1

Mr. Dowel1 is Market Development Manager for Motorola. Mr. Dowel1 managed Motorola's ADVANCE Project activities for the IVHS Strategic Business Unit (SBU) from 1993 through 1995. This SBU was responsible for design, development, manufacture, installation and maintenance of the ADVANCE in-vehicle navigation and route guidance system as well as the radio frequency communications system. Mr. Dowel1 also served as the main Motorola official responsible for resolution of institutional issues related to contracts, audits and procurement procedures. His current business unit is responsible for successfully launching the world's first production emergency call system that marries GPS positioning with cellular communications.

Syd Bowcott

Mr. Bowcott is the Chief Engineer for ITS Programs for De Leuw, Cather & Company. He led the De Leuw, Cather & Company team which functioned as the lead systems engineer and had overall responsibility for system integration.

1.3 Intended Audience

This paper is intended to provide useful information for those interested in the institutional issues of implementing a complex, technologically oriented project involving a wide variety if participants, It is intended for project managers and system developers that have a basic understanding of the project institutionally as well as technically in order to aid in the development of similar ITS systems.

1.4 References

The following reports and documents would be of interest to the reader desiring further information on *ADVANCE* and institutional issues:

- IVHS Institutional Issues and Case Studies - ADVANCE Case Study, DOT-VNTSC-FHWA-94-9, March 17, 1994 , Science Applications International Corporation for Volpe National Transportation Systems Center
- Scope, Feasibility and Cost of a Dynamic Route Guidance System Demonstration, August 1990, Motorola
- IVHS Agreement for ADVANCE, dated July 9, 1991
- First Amendment to the IVHS Agreement for *ADVANCE,* dated March 11,1994
- *ADVANCE* MNA Operator Manual - Release 1.5, Document No. 8800
- MNA Visor Card, January 1995, Motorola
- Driver Participation Agreement
- Driver Waiver & Release Form
- Vehicle Maintenance Log
- Vehicle Utilization Form
- Vehicle Information Table
- Familiar Driver Checkin and Checkout Logs
- Procedures for Vehicle Breakdowns and Accidents

1.5 Report Organization

This report presents the Introduction in Section 1; the Purpose of This Report in Section 2; the Findings in Section 3; and the Summary of Recommendations in Section 4.

2.0 PURPOSE

This report is intended to document the institutional challenges face in the development and deployment of *ADVANCE* and its subsystems. While other reports deal with technical challenges encountered in the design and operation of *ADVANCE*, this report concentrates on the institutional challenges encountered, what impact they had and how they were met.

It is intended that this report will be useful to others that are currently involved in or will be involved in developing sophisticated Intelligent Transportation Systems.

3.0 METHODOLOGY AND FINDINGS

3.1 Feasibility Study

The major institutional issues for *ADVANCE* involved the progression of a technological effort from concept to reality. The original *ADVANCE* concept was defined in the report entitled "Scope, Feasibility and Cost of a Dynamic Route Guidance System Demonstration" issued in August 1990. This report was a joint feasibility study of the conceptual design of *ADVANCE* undertaken by Motorola and the Illinois Universities Transportation Research Consortium (IUTRC) on behalf of the Illinois Department of Transportation (IDOT).

3.2 IVHS Agreement for the *ADVANCE* Project

The feasibility study served as the initial step in the development and implementation of the *ADVANCE* Project. Extensive contract negotiations between the four *ADVANCE* Parties (FHWA, IDOT, Motorola, and IUTRC) occurred following the completion of the feasibility study. The July 9, 1991 IVHS Agreement for the *ADVANCE* Project established the mutually agreeable terms to engage in this cooperative demonstration to design, develop, implement and evaluate *ADVANCE* The Agreement outlined overall policy and program goals, individual Party responsibilities, committee structures, project management roles, project length and funding terms, and other basic contractual provisions (i.e. termination, property rights, liability, etc.). While this Agreement represented the general terms and conditions, it was recognized that provisions of the Agreement would be implemented through subsequent contracting documents.

3.3 Complexities with Implementing IVHS Agreement

While the IVHS Agreement for the *ADVANCE* Project served as the guiding contractual document, several complexities arose in the implementation of the Agreement. These complexities resulted from the following:

(1) **The General Nature of the Agreement.** Situations that arise during the implementation of a project are oftentimes not specifically covered by the terms of an overall Agreement. However, the overall Agreement provides a blueprint for a project to follow. In *ADVANCE,* the overall Agreement was required to achieve consensus among the Parties.

(2) **Relationship of the Overall IVHS Agreement to Specific Agreements Subsequently Executed with Each Party.** The basic terms of the Agreement between IDOT (Project Manager for *ADVANCE)* and IUTRC were fairly routine to negotiate. The major differences were related to individual budget submittals and

invoice support documentation. The payments to IUTRC required a different level of record keeping compared to previous IUTRC contracts executed with IDOT. After many discussions between Project and IUTRC administrative staffs, each IUTRC invoice contained the necessary support records to justify payment and document the IUTRC contribution to *ADVANCE*

The contractual relationship with Motorola was much more complex to establish. The Motorola IVHS Strategic Business Unit (SBU) which led their effort in *ADVANCE* possessed very strong historical experience dealing with commercial enterprises, but very little practical experience with governmental units. The Motorola IVHS SBU believed that execution of the overall IVHS Agreement for the *ADVANCE* Project would enable them to submit work orders for their product development responsibilities in the overall Agreement. Motorola began preparing individual work orders that contained schedules and budgets for their deliverables. They believed IDOT would be able to promptly sign these work orders and allow Motorola to submit invoices for the price of individual items produced. Motorola was unaware that IDOT would require a specific agreement between the two parties (IDOT and Motorola) before the work orders could be reviewed and approved.

Federal and state regulations require a basic agreement between contractual parties before funding is provided for transportation projects. After lengthy negotiations, an Agreement for Technical Services was executed between IDOT (Project Manager for *ADVANCE)* and Motorola on October 28, 1992 which included the basic contract provisions, including time of performance and compensation. The execution of this Agreement allowed IDOT and Motorola to prepare and negotiate individual work orders for each product deliverable. Subsequent amendments to this Agreement were also executed to extend the period of performance, provide supplemental compensation, and add provisions that were required later by legislative actions.

(3) Leadership Changes Among the *ADVANCE* Parties After Execution of IVHS Agreement

A significant number of leadership changes among the *ADVANCE* Parties created difficulties for philosophical continuity and consistency to implement the negotiated IVHS Agreement for the *ADVANCE* Project. A recommendation for future ITS projects is to put forth the greatest effort possible to make sure that key project leaders are retained from the point of project conception to completion.

(4) Delicate Project Management Role

The IVHS Agreement for the *ADVANCE* Project placed IDOT in a dual role of a Party on the Steering Committee and Project Manager. With this dual role, there were several instances where key IDOT project management decisions required to be balanced with its partnership role. A suggestion for future ITS projects is that the project manager's role be distinct and separate from the project partners.

(5) **Continuous Involvement of Respective Legal and Financial Staffs**

In *ADVANCE*, the project leaders negotiated the initial IVHS Agreement and gave their respective legal and financial staffs the responsibility to implement the Agreement, In a few situations, the legal and financial staffs encountered contractual language that differed from regular organizational policy and they were not familiar with its genesis. It is recommended that key legal and financial personnel be involved in future ITS projects from the initial project negotiation through project completion phases.

(6) **Define Procurement Processes Before Executing Agreements**

The process for procuring equipment from Motorola was only conceptually discussed prior to execution of the IVHS Agreement for the *ADVANCE* Project. A more defined procurement process would have eliminated some obstacles that occurred in the implementation of the *ADVANCE* Project. It is recommended that future ITS projects fully detail the procurement process with commercial enterprises before executing an agreement.

(7) **Evolving Changes to IVHS Agreement for the *ADVANCE* Project**

As with other contracts, the IVHS Agreement for the *ADVANCE* Project required amendments to be consistent with changes in project responsibilities, timing and funding. It is important that ITS projects designate a certain position title that would be responsible for executing all contractual documents.

3.4 Valuation of Private Sector Contributions

According to the IVHS Agreement for the *ADVANCE* Project, all Parties, except FHWA, could singly and/or collectively, solicit support from other private sources to insure that the total project could obtain and maintain the private sector funding share over the life of the project. This support could be in the form of money, equipment, facilities or services. Such support was included in the private sector share for the Party that solicited the contribution and the Project as a whole.

The *ADVANCE* Project instituted equitable and well-documented procedures to value these outside private sector contributions. For example, all proposals from outside private sector firms offering significantly reduced prices on equipment and/or services were brought forth to the *ADVANCE* Participation and Administration (P&A) Subcommittee for review and approval. The contributions were valued at the difference between General Services Administration (GSA) or equivalent prices and the price charged to *ADVANCE.* Outside private sector staff assistance was approved only after upon submittal of detailed support documentation. Valuation of the *ADVANCE* Project vehicle fleet was based upon the equivalent of a lease price covering a specified period of time and mileage consumed.

The input of the P&A Subcommittee was critical to the valuation of these outside private sector contributions and their worth to the *ADVANCE* Project. It is recommended that future ITS projects organize a similar administrative-type group to handle these issues.

3.5 Insurance Issues for the *ADVANCE* Fleet and Recruited Drivers

Various automobile manufacturers (Ford, General Motors, Mercedes-Benz, Toyota, Nissan, Volvo, Honda, and Peugeot) loaned vehicles for use in the testing and Targeted Deployment of the *ADVANCE* Project. A total of twenty-four (24) vehicles were provided. An additional eight vehicles were obtained through a rental agreement between Argonne National Laboratory (ANL), the Evaluation Manager for *ADVANCE* and Ace Rent A Car.

The first group of six vehicles were assigned to the *ADVANCE* Project Office in March 1994. Prior to the receipt of these vehicles, the *ADVANCE* Project Office contacted several insurance companies and requested they submit a quote for insuring this fleet. The requested quote was based upon the following provisions:

(1) Liability limits of $1 ,000,000 per accident for bodily injury and property damage.
(2) Uninsured/underinsured motorist coverage of $1 ,000,000 per accident.
(3) $5,000 per person coverage for medical payments.
(4) $500 deductible for collision coverage.
(5) $500 deductible for comprehensive coverage.

Most insurance companies were reluctant to provide a quote because of the uniqueness of the *ADVANCE* in-vehicle route guidance system and the minimal experience associated with the operation of in-vehicle navigational devices. A small number of firms (less than five) proposed insurance premium quotes that varied significantly because of the lack of familiarity with an *ADVANCE-type* system.

Each of the *ADVANCE* Parties was concerned about their potential financial liability with operation of the *ADVANCE* fleet. In an attempt to safeguard the financial interests of the *ADVANCE* Parties, the Project Office worked diligently to secure insurance coverage according to the terms outlined above. The insurance policy needed to cover multiple drivers including employees of the *ADVANCE* Parties, other participants, guests/visitors, and motorists from the general public. The *ADVANCE* insurance policy served as the primary coverage for the insured vehicles.

The firm selected to provide the insurance coverage served the Project well. At the same time, the actual loss experience for the *ADVANCE* fleet has been minimal over the more than two years of operation. Only one accident involving *an ADVANCE* fleet vehicle was the fault of an *ADVANCE* driver and the cause of this accident was not related to operation of the in-vehicle navigation equipment. The minimal actual loss experience was partially due to precautions taken by the Project in assigning the *ADVANCE* vehicles. The policy instituted by the Project included the following procedures:

(1) Drivers were required to sign a waiver and release form whereby they agreed to follow the rules of the road and waive any claim against the *ADVANCE* Parties in connection with the use of the vehicle.

(2) Drivers certified they had a valid drivers license and presented such valid license before a vehicle was issued.

(3) Drivers were also required to certify their driving records would authorize them to operate a vehicle according to general guidelines established by the *ADVANCE* Project. The general guidelines included:

   (a) The driver never having had a license suspended, revoked or canceled.
   (b) Limitations on the number of moving violations issued to the driver.
   (c) The driver never having had been convicted for driving under the influence of alcohol and/or drugs, leaving the scene of an accident, or transporting controlled substances while in the physical control of a motor vehicle.
   (d) A verification that the driver had no physical disability or disease that would have impaired his/her ability to operate a motor vehicle.
   (e) A verification that the driver possessed at least the minimum insurance coverages required by Illinois law for vehicles registered in his/her name.

A relationship was established with the Illinois Secretary of State's Office to electronically check the driving records of all potential *ADVANCE* drivers licensed in Illinois. A subcontractor (The Blackstone Group) for De Leuw, Cather & Company coordinated these driver license checks with the Secretary of State's Office. The procedure consisted of Blackstone representatives submitting names and driver license numbers for each potential *ADVANCE* driver to the Secretary of State's

Office who in turn provided a copy of each driver abstract to Blackstone. The driver abstract was then reviewed for recorded traffic violations. Specified criteria were used to guide this review of driver abstracts. These criteria were mentioned earlier in this section. If a potential driver's record contained a violation history that did not adhere the established guidelines, he/she failed the screening procedure and was not allowed to operate an *ADVANCE* vehicle. The driver license review procedure for Illinois licensed drivers and the required written certification for drivers licensed outside of Illinois provided assurances to *ADVANCE* and our insurance carrier that all drivers met the minimum guidelines established by the Project.

Some potential drivers recruited by the universities to perform field data collection activities as part of the ADVANCE Targeted Deployment evaluation voiced displeasure with the language contained in the waiver and release form. As a result, they refused to continue to participate in the data collection program. While it was regrettable that the driver pool was diminished, the Parties' legal staffs required the waiver and release language to limit the liability of the Parties.

As noted above, the insurance issues were complex, even in the *ADVANCE* Project where the distribution and assignment of the vehicle fleet was controlled. Recruited private drivers that participated in the familiar driver test only operated an *ADVANCE* vehicle for a two-week period. At the end of two weeks, the vehicle was returned and assigned to another household. With the use period limited to a couple of weeks, the opportunity for equipment theft and/or damage was minimized.

Insurance coverage should be a high priority for future ITS projects that involve the operation of motor vehicles. Potential drivers need to be made aware of their risks and responsibilities in operating a vehicle. A policy for checking driving records must be in place as early as possible so that all records are checked before an individual is allowed to operate a vehicle. While the agreements signed by prospective drivers need to be understandable, they must offer sufficient protection to project partners in terms of liability.

The insurance issues associated with operation of fleet vehicles in a controlled environment with the *ADVANCE* Targeted Deployment approach are much less significant than those that would be encountered in a full-scale ITS deployment. The original *ADVANCE* concept provided for the installation of 3,000-5,000 Mobile Navigation Assistant (MNA) units in private and commercial vehicles. When the driver recruitment procedures were being established in the early stages of *ADVANCE*, significant time and financial resources were committed to addressing insurance and liability issues for both private and commercial drivers. The insurance and liability issues were much more complex compared to the *ADVANCE* Targeted Deployment because MNA equipment was to be installed in vehicles owned and operated by the volunteer participants. In addition, the *ADVANCE* equipment was going to remain in a participant's vehicle for up to eighteen (18) months.

3.6 Fleet Operation Issues

As the *ADVANCE* fleet vehicles were delivered for evaluation testing and Targeted Deployment familiar driver use, the Project Office addressed several fleet operation issues in addition to insurance. Comprehensive procedures were instituted that included the following specific steps:

(1) Log sheets were prepared for each vehicle that included the next service date for vehicle maintenance.

(2) A daily log for each vehicle was retained. This log included the beginning and ending mileage figures for each vehicle. The logs were used to prepare the vehicle utilization forms that were distributed to each of the IUTRC drivers hired to perform evaluation testing. A log was also prepared before each familiar driver received a fleet vehicle for a two-week period.

(3) A table was prepared that contained all important information for each vehicle, including vehicle make/model, year, license plate number, color, registration expiration date, credit card number, cellular phone number, American Automobile Association (AAA) membership number, and RF modem number. This table represented a quick reference source to identify a specific fleet vehicle.

(4) Daily early morning meetings were conducted during the *ADVANCE* Targeted Deployment to address vehicle problems encountered in the previous day of testing. These problems were related to vehicle mechanical difficulties and/or MNA system operating malfunctions. If a vehicle or MNA problem existed, the vehicle was road tested immediately before being allowed back into service.

3.7 Major ADVANCE Lessons

While the full scale deployment of the *ADVANCE* concept was not undertaken, many important lessons were learned in the planning for such an activity. These lessons could provide valuable assistance for future ITS projects. Some of the major lessons include:

(1) Drafting and executing a Driver Participation Agreement that:

(a) Makes the driver responsible for the safe operation of the vehicle.
(b) Protects the Project in terms of liability for minor cosmetic alterations that occur during the installation of the in-vehicle equipment.
(c) Specifies the length of time equipment will be used.
(d) Requires notification to the Project if any lawsuits or claims related to the in-

vehicle equipment are made against the driver.

(e) Allows for inspection of the vehicle and equipment for evaluating, repairing, and upgrading equipment.

(f) Requires the participant to be responsible for damage to in-vehicle equipment caused by intentional or wanton actions, or those caused by unregistered drivers.

(g) Requires the driver to maintain a specified level of liability coverage for the automobile insurance policy that meets or exceeds state law.

(2) Provision of sufficient information to the driver about the project.

The *ADVANCE* Targeted Deployment (and the plans for a full scale deployment) provided drivers with a MNA Operators Manual, visor instruction cards, and recommendations on how to handle any unique situations, including accidents, vehicle breakdowns, etc. With the planned full scale deployment where units would be installed in non-fleet vehicles, issues such as households moving out of the project area, vehicle sales or title transfers, complexities involving leased vehicles, and possible automobile repossession would challenge managers even further.

(3) Providing assistance for malfunctioning vehicles or navigational equipment.

Under the *ADVANCE* Targeted Deployment, staff members were available during all hours when the Traffic Information Center (TIC) was operating (6:00 a.m.-7:OO p.m.) weekdays to assist drivers who were experiencing problems with the *ADVANCE* equipment. Also, in the case of vehicle breakdowns, each *ADVANCE* fleet vehicle contained an AAA-Chicago Motor Club (CMC) Plus card for 24-hour roadside assistance that included free towing to a repair facility within 100 miles of the vehicle breakdown.

Under the planned *ADVANCE* full scale deployment, a Help Center under the operation of AAA was to be activated to provide drivers with advice through the use of a toll free telephone number. This Help Center approach would have attempted to solve MNA operational malfunctions. If the problem could not be handled over the telephone, the driver would have been referred to an authorized Motorola service center representative for resolution.

Any future ITS project should implement vehicle and equipment repair procedures similar to those employed in *ADVANCE* so that project participants may receive needed assistance in a timely fashion. A large scale deployment will create the need for additional staff and financial resources compared to the *ADVANCE* Targeted

Deployment to respond to vehicle and equipment repairs/breakdowns. The *ADVANCE* success in this area resulted from the contribution of resources by private sector participants such as AAA. These contributions helped conserve staff and financial resources and alleviated much stress during deployment.

(4) Procurement/Audit Issues with Private Sector Participants

As mentioned earlier in this paper, significant effort was required to execute the IDOT/Motorola Agreement for Technical Services and the accompanying work orders for products that Motorola was providing under this Agreement. This unique public/private sector agreement represented an entrance into previously uncharted waters for both IDOT and Motorola. IDOT and the FHWA required assurances that the prices being charged by Motorola were accompanied by adequate support documentation for expenses incurred. At the same time, Motorola required implementation of a system that allowed record keeping according to their commercial business practices.

The three parties entered into thorough and lengthy discussions to develop a procedure entitled "*ADVANCE* Project Motorola Route Guidance Program-Audit Program". This audit program, which was finalized on July 29, 1993, served as the foundation for the third party audit of Motorola financial records pertaining to the ADVANCE Project. The audit program contained the purpose and scope of the audit, audit approach and audit program steps.

Subsequent to the approval of this audit program, an audit Request for Proposal (RFP) was prepared and distributed to auditing firms interested in conducting the Motorola audit. The language for the audit RFP was approved in November 1994. Bids were received from seven prospective firms in December 1994, and a contract was executed on January 27, 1995 to perform this audit.

Even though all parties worked diligently to develop a well-defined and comprehensive audit program, the actual implementation of the program was hampered because the parties had varying interpretations regarding the language contained in the program. The auditors, after reviewing the audit RFP and the audit program, constructed a set of audit procedures they believed would allow for performance of the assigned tasks contained in their contract with IDOT. These procedures included review of some support records that Motorola believed were not within the scope of the July 1993 Audit Program. Due to the willingness of respective staffs from the auditors and Motorola to work through the varying interpretations of the audit program, a final audit report was completed in February

1996. This audit report allowed IDOT to pay Motorola for products they delivered under the IDOT/Motorola Agreement for Technical Services. However, the inability to foresee problems in implementing the agreed to Audit Program necessitated a contract amendment with the independent auditor that contained a sizable increase in compensation and lengthened period of performance to complete their assigned tasks. The complexities involved in completing the audit report also forced minor delays in payments due Motorola under the Agreement for Technical Services.

There are many lessons to be learned in the development of procurement and audit procedures for a project that combines a private sector firm with a commercial focus and governmental agencies with a regulatory focus. These lessons include:

(a) All parties must interpret key terms the same. For example what governmental agencies refer to as "costs" the private sector uses the term "prices". When government agencies use the term "reimbursement", the private sector considers this to be "payment". Future ITS projects should consider the creation of a glossary that includes definitions for these key terms.

(b) Any agreed to procedures must attempt to cover all possible implementation scenarios. While the Parties in *ADVANCE* spent significant time developing the July 1993 Audit Program, a couple of differences in interpretation resulted in sizable delays for completion of the audit. In hindsight, *ADVANCE* learned it is better to err on the side of conservatism and develop a program that is more comprehensive to avoid future problems in implementation.

(c) The governmental agencies need to better understand the business focus of the private sector entities they are working with. The private sector needs to understand the legal requirements of government agency contracting. While several divisions (units) of Motorola have a long-standing contractual relationship with governmental agencies, the Motorola IVHS SBU which was leading the development of the *ADVANCE* system had little experience dealing with governmental agencies. At times, the governmental agency requirements and the Motorola commercial focus did not totally coincide. A smoother relationship could be forged if the corporate cultures of all major participants are recognized and understood prior to contract execution.

(5) Roles of Project Partners

The IVHS Agreement for the *ADVANCE* Project included individual Party responsibilities based upon each Party's area of interest. A major lesson learned during the *ADVANCE* Targeted Deployment is to match the responsibilities of each Party with their respective talents. For example, if a Party possessed strengths in designing a program, this did not necessarily mean they were best equipped to carry out the program. Future ITS projects should attempt to recognize the strengths and weaknesses of each partner prior to beginning a project and assign responsibilities to maximize these strengths.

The complex responsibilities associated with ITS-related efforts requires strong communication between project partners to achieve program success. Future ITS projects should seriously consider housing a lead representative from each partner in the same facility or in close proximity to each other to enhance communication.

At times, the institutional issues encountered in *ADVANCE* caused minor the Project delays because they caused uncertainty in completing administrative responsibilities according to schedule. However, despite these obstacles, the Parties made the commitment to work together to satisfactorily complete the goals and objectives established for the Project. Equally important, the institutional issues identified and resolved in *ADVANCE* will serve as valuable lessons for future ITS projects.

4.0 SUMMARY

Several very important recommendations can emanate from this review of institutional issues encountered during *ADVANCE* These recommendations for future ITS projects include the following:

(1) Maintain routine and open communication lines between Project management staff and all public and private sector participants. Oftentimes, lengthy negotiations are necessary to resolve complex and delicate issues.

(2) Provide the greatest effort possible to make sure that key project leaders are retained from the point of project conception to completion.

(3) Make the project manager's role distinct and separate from those of the project partners.

(4) Involve key legal and financial personnel from the initial project negotiation through project completion phases.

(5) Fully develop and understand all procurement processes with commercial enterprises before executing an agreement.

(6) Require each participant to designate a certain position that would be responsible for executing all contractual documents.

(7) Organize administrative-type committees among the major parties that can handle important non-engineering issues.

(8) Place a high priority on insurance coverage for projects that involve the operation of motor vehicles. Potential drivers need to be made aware of their risks and responsibilities in operating a vehicle.. A policy for checking driving records must be in place as early as possible so that all records are checked before an individual is allowed to operate a vehicle. While the agreements signed by prospective drivers need to be understandable, they must offer sufficient protection to project partners in terms of liability.

(9) While the full scale deployment of the *ADVANCE* concept was not undertaken, many important lessons were learned in the planning for such an activity. Some of the major lessons include:

(A) Drafting and executing Driver Participation Agreements that:

(1) Make the driver responsible for the safe operation of the vehicle.
(2) Protect the Project in terms of liability for minor cosmetic alterations that occur during the installation of the in-vehicle equipment.
(3) Specify the length of time equipment will be used.
(4) Require notification to the Project if any lawsuits or claims related to the in-vehicle equipment are made against the driver.
(5) Allow for inspection of the vehicle and equipment for evaluating, repairing, and upgrading equipment.
(6) Require the participant to be responsible for damage to in-vehicle equipment caused by intentional or wanton actions, or those caused by unregistered drivers.
(7) Require the driver to maintain a specified level of liability coverage for the automobile insurance policy that meets or exceeds state law.

(B) Provide sufficient information to drivers about the project.

The *ADVANCE* Targeted Deployment (and the plans for a full scale deployment) provided drivers with an MNA Operators Manual, visor instruction cards, and recommendations on how to handle any unique situations, including accidents, vehicle breakdowns, etc.

(C) Provide assistance for malfunctioning vehicles or navigational equipment.

Under the *ADVANCE* Targeted Deployment, staff members were available during all hours when the Traffic Information Center (TIC) was operating (6:00 a.m.-7:OO p.m.) weekdays to assist drivers who were experiencing problems with the *ADVANCE* equipment. Also, in the case of vehicle breakdowns, each ADVANCE fleet vehicle contained an AAA-Chicago Motor Club (CMC) Plus card for 24-hour roadside assistance that included free towing to a repair facility within 100 miles of the vehicle breakdown.

Under the planned ADVANCE full scale deployment, a Help Center under the operation of AAA was to be activated to provide drivers with advice through the use of a toll free telephone number.

Any future ITS project should consider implementing vehicle and equipment repair procedures similar to those employed in ADVANCE so that project participants may receive needed assistance in a timely fashion. A large scale deployment will create the need for additional staff and financial resources compared to the *ADVANCE* Targeted Deployment to respond to vehicle and equipment repairs/breakdowns. The number of administrative tasks associated with vehicle maintenance during the ADVANCE Targeted Deployment would have strained staff resources to the limit if not for the contribution of resources by private sector participants such as AAA.

(D) Develop procurement and audit procedures for the project that meet the internal requirements of a private sector firm with a commercial focus and of governmental agencies with a regulatory focus. To achieve this mutual project focus:

(1) All parties must interpret key terms the same. Future ITS projects should consider the creation of a glossary that includes definitions for these key terms.

(2) Any agreed upon procedures must attempt to address all possible implementation scenarios.

(3) The governmental agencies need to better understand the business focus of the private sector entities they are working with. The private sector needs to understand the legal requirements of government agency contracting.

(E) Recognize the roles of the project partners and matching the responsibilities of each Party with their respective talents. Future ITS projects should attempt to recognize the strengths and weaknesses of each partner prior to beginning a project and assign responsibilities to maximize these strengths.

(F) Develop routine and open communication between project partners to achieve program success. Future ITS projects should seriously consider housing a lead representative from each partner in the same facility or in close proximity to each other to enhance communication.

At times, the institutional issues encountered in ADVANCE caused minor delays in the Project because they caused uncertainty in completing administrative responsibilities according to schedule. However, despite these obstacles, the Parties made the commitment to work together to satisfactorily complete the goals and objectives established for the Project. Equally important, the institutional issues identified and resolved in ADVANCE will serve as valuable lessons for future ITS projects.

APPENDIX J

IMPLEMENTATION OF ALGORITHMS
IN A
REAL WORLD ENVIRONMENT:
THE ADVANCE EXPERIENCE

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IMPLEMENTATION OF ALGORITHMS IN A REAL WORLD ENVIRONMENT: THE *ADVANCE* EXPERIENCE

EXECUTIVE SUMMARY

Development and implementation of new traffic analysis algorithms in a real world application environment with a fixed time schedule requires coordination and collaboration among algorithm developers, implementation programmers, developers and installers of the technology to be used for data collection and communication and the operators of the implemented system. Effective management of this process requires a carefully structured work program which includes adequate time for completion of all required tasks and which recognizes interdependencies among tasks. This work program must be flexible enough to respond to changes inherent in the development of technology or algorithms.

Effective management also requires coordination to ensure that all participants are working to meet the commonly agreed objectives of the program. This can be accomplished, in part, by maintaining a high level of communication among parties through regular meetings of all groups involved in the development and implementation activities but also requires a strong decision making capability to resolve potential conflicts among the work of distinct groups.

A further issue in the development, estimation, validation and refinement of algorithms is the availability of data to support these activities. Such data are required early in the algorithm development process. If such data are not available from field data collection, simulation data can be used to support initial development. However, field data are required for final validation and refinement. If the collection of such data requires use of the implementation system, as in the case of *ADVANCE* the order of development of system components should include provisions for such data collection after the implementation of all operational systems, at least on a prototype basis, and time to use such data for algorithm validation and refinement before final implementation.

This paper describes the procedures undertaken to maintain coordination among developers, program implementors and operators and describes implementation problems which arose and their treatment. It also describes the use of simulation data for initial development and highlights the importance of field data for final refinement and validation.

This demonstration also indicates that the traffic analysis algorithms developed have strong potential to diagnose traffic flow conditions and provide information to vehicles and their drivers in a real time environment.

IMPLEMENTATION OF ALGORITHMS IN A REAL WORLD ENVIRONMENT: THE *ADVANCE* EXPERIENCE

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1.0 INTRODUCTION

A central component of the *ADVANCE* demonstration program is the use of probe vehicles to gather data and transmit them to a Traffic Information Center (TIC) where the data are interpreted to obtain estimates of current travel time, diagnostic information about current traffic flow conditions and forecast information about travel time for a limited period into the future. The diagnostic information and travel time forecasts are screened for importance and transmitted to equipped vehicles which screen the data for relevance and use these data to provide drivers with alternative route plans and route diversion information. An overview description of the *ADVANCE* demonstration program and the manner in which the *ADVANCE* data collection, communication, data interpretation, data broadcast to equipped vehicles and use of data for route planning is in the *ADVANCE* System Definition Document - Final Implementation Definition (1995).

The use and interpretation of data in the *ADVANCE* environment are undertaken by a system of algorithms for Traffic Related Functions (TRF) which analyze and interpret automatically collected data and provide the results to participating vehicles. The structure and function of the TRF component algorithms are described in Section 3.2.

This paper documents how the algorithm developers, the University of Illinois at Chicago Urban Transportation Center (UIC-UTC) and the Northwestern University Transportation Center (NUTC), undertook and organized the development and integration of the TRF algorithms. The development process described was undertaken in coordination with the Electrical Engineering Computer Science Department at the University of Illinois (UIC-EECS), which was responsible for implementation of the Traffic Information Center (TIC) including the TRF algorithms; Motorola Corporation, which developed the Mobile Navigation Assistant (MNA); and the Illinois Department of Transportation and DeLeuw Cather Company, its systems integration contractor, which provided coordination and overall project management. The paper describes issues which arose in the development of TRF algorithms, the methods adopted to address these issues and their effectiveness and concludes with finding which may be useful to future developers of traffic analysis algorithms in the Intelligent Transportation System (ITS) context.

1.1 Acronyms and Definitions

All acronyms and definitions used in this document that are specific to the *ADVANCE* project and therefore potentially unfamiliar to the reader are defined in the System Definition Document: #8020.ADV.06. This document is available for examination and acquisition through the Internet at **http://ais.its-program.anl.gov/.** These and other acronyms are defined upon their first use in this report.

1.2 Authors

Contributing authors to this paper are:

Frank S. Koppelman, Professor of Civil Engineering and Transportation, McCormick School of Engineering, Northwestern University. Dr. Koppelman has been affiliated with the Northwestern University Transportation Center (NUTC) for over twenty years and has published numerous papers and journal articles in the field of transportation planning and analysis. Dr. Koppelman was involved in the development of the original *ADVANCE* deployment concept, as a member of the Illinois University Transportation Research Consortium, and has been involved in a number of aspects of the *ADVANCE* Demonstration including the development of incident detection algorithms.

Ashish Sen, Professor of Urban Planning and Policy, Mathematics, Statistics and Computer Science at the University of Illinois at Chicago (UIC), is the Acting Director of the Urban Transportation Center (UTC) and Director of the Statistics and Evaluation Laboratory at UIC. Professor Sen was responsible for the design of several components of the traffic related functions (TRF) component of *ADVANCE*. Professor Sen shares responsibility with Professor Siim Soot and Dr. Berka for evaluation of *ADVANCE* prediction algorithms with the exception of incident detection. Professor Sen has been on the UIC faculty for over 25 years and received his doctorate from the University of Toronto.

Stanislaw Berka, Research Associate at Portland State University, who was doctoral student and graduate research assistant at (UIC-UTC) from 1990 through 1995. Berka had extensive involvement with *ADVANCE* beginning with the definition of the demonstration area and continuing with primary responsibility for the design and implementation of the TRF Base Data (BD) component. Berka completed his dissertation based on this work in Fall, 1994, and continued to work for the *ADVANCE* program at UIC-UTC as a Post-Doctoral Research Associate. His responsibilities included the final design and development of the TRF Data Fusion (DF) sub-component as well as coordination of the design for all TRF sub-components.

1.3 Intended Audience

This report should be of interest to individuals or organizations concerned with the development and implementation of real-time traffic data analysis tools in an application environment. It is intended to describe the process and interpret, from the perspective of hindsight, some of the more instructive experiences in the development and implementation of traffic analysis algorithms in an application environment with a view towards identifying issues which should be addressed, confronted and resolved by other developers in the future.

1.4 References

Readers are encouraged to consult the references listed below to obtain additional and detailed information according to their needs and interests. These references, some of which can be found on the Internet page cited above, are grouped in six categories as follows:

(1) Traffic related functions overview documents

- System Definition Document - Initial Concept #8020.ADV.06-2.0, September 29, 1995
- System Definition Document - Final Implementation Document, #8020.ADV.06-2.0, September 29, 1995

(2) Base data related documents

- S. Berka, D.E. Boyce, J. Raj, B. Ran, A. Tarko, and Y. Zhang, A Large-Scale Route Choice Model with Realistic Link Delay Functions for Generating Highway Travel Times, report to Illinois Department of Transportation, Urban Transportation Center, University of Illinois, Chicago, 1994.
- A. Tarko, S. Berka, and X. Fengman, Creation of the *ADVANCE* Network Attribute Database, *ADVANCE* Working Paper Series, 41, Urban Transportation Center, University of Illinois, Chicago, 1994.

(3) Static profile related documents

- Static Estimates of Travel Times in *ADVANCE* Release 1.6 Algorithm Report and Detail Design Document (#8600), M.D. Mathes and A. Sen -*ADVANCE* WORKING PAPER Series Number 40, January 1995.
- P. Thakuriah, A. Sen and M.D. Mathes, Static Estimates of Travel Times in *ADVANCE*, Release 1.6, *ADVANCE* Working Paper #39.

(4) Data Fusion related documents

- S. Berka, X. Tian, and A. Tarko, Data Fusion Algorithm for *ADVANCE* Release 2.0, *ADVANCE* Working Paper Series, 48, Urban Transportation Center, University of Illinois, Chicago, May 1995.
- V. Sisioupiku, N.M. Rouphail and A, Santiago, "Analysis of the correlation between arterial travel times and detector data from simulation and field studies," Preprint no. 940488, Transportation Research Board Annual Meeting, Washington, DC, January 9-13, 1994.

(5) Travel time prediction related documents

- A. Sen, P. Thakuriah and N. Liu, Design of the Travel Time Forecasting Procedure, *ADVANCE* Working Paper #3 1.
- N. Liu and A. Sen, Dynamic TT Prediction in *ADVANCE:* Modified Release 1.5 TTP Algorithm Report and Detail Design Document *ADVANCE* Working Paper #46.
- N. Liu and A. Sen, Travel Time Prediction Algorithm for *ADVANCE:* Release 2 AD *VANCE* Working Paper #47.

(6) Incident detection related documents

- N. Bhandari, V. Sethi, F.S. Koppelman and J.L. Schofer, Calibration of Fixed Detector and Probe Vehicle Algorithms with Initial Field Data, *ADVANCE* Technical Report TRF-ID-20 1, March 17, 1995.
- V. Sethi, C. Flannery, F.S. Koppelman and J. L. Schofer, Duration and Travel Time Impacts of Incidents, Technical Report TRF-ID-202, November 4, 1994.
- N. Bhandari, V. Sethi, F.S. Koppelman and J.L. Schofer, Incident Detection Algorithms for Release 2.0, Technical Report TRF-ID-206, June 2, 1995.
- F.S. Koppelman and S. Tsai, Revised Incident Detection Algorithms for Release 2.0 and Re-Calibration of Arterial Fixed Detector Incident Detection Parameters, Technical Report TRF-ID-300/400, Final Report, August 3, 1996.
- F.S. Koppelman, C-H. Wen, W-H. Lin and T-S. Peng, Evaluation of Arterial Probe Vehicle and Fixed Detector and Expressway Fixed Detector Incident Detection Algorithms, *ADVANCE* Project Document #8461 .OO, Draft Final Report, July 25, 1996.

1.5 Report Organization

This report consists of four major sections. This section is the introduction. Section 2 discusses the purposes of the paper. Section 3 presents a description of the approaches and methods used and an overview of the findings. Section 4 provides a summary and a compendium of the lessons learned.

2.0 PURPOSE

The Traffic Related Functions (TRF) algorithms of *ADVANCE* process data, primarily from probe-vehicles and fixed detectors, to infer traffic flow conditions which can be used for vehicle route guidance. The interpretation of the data to infer traffic flow conditions is a central component of ADVANCE and is likely to be a central component of all or most future Advanced Traveler Information Systems (ATIS). The purpose of this paper is to describe the approach taken to the development of the TRF Algorithms. This description of the approaches taken, problems which arose and how they were resolved and the results obtained may provide guidance to others in the development of application algorithms in an environment which is constrained both in time and data resources.

3.0 METHODOLOGY AND FINDINGS

This section consists of four subsections. The first of these briefly describes the background of the *ADVANCE* project; the second provides an overview of the TRF algorithm structure; the third describes three issues which impacted the TRF development process, how they were resolved in *ADVANCE* and implications for future ATIS projects; and the last section describes the potential for future development of traffic analysis algorithms in this or other contexts.

3.1 Background

The deployment of *ADVANCE* traveler information systems (ATIS) is dependent on the acquisition of real-time traffic flow data, the interpretation of that data to infer the characteristics of traffic flow on the network, and the communication of these characteristics, in useable form, to potential users. The data sources include *ADVANCE* equipped probe vehicles, which collect and report their travel time while traversing the road network in the test area, and in-pavement sensors, which measure volume and occupancy on selected roadways within the test area. These data are compared to historic information describing the expected range of values for comparable data; this comparison provides the basis to identify abnormal traffic flow conditions. The information about abnormal traffic flow conditions is provided to *ADVANCE* Mobile Navigation Assistants (MNA) which uses it to select preferred travel routes or to propose route diversions. In the *ADVANCE* design, the normal travel service conditions are stored on-board the probe vehicle in the form of expected link travel times for selected periods for each day type. These normal service data, which are updated periodically, are used for route finding unless modified due to reports of current conditions from the TRF algorithms.

The focus of this paper is on the development of algorithms which can be used to create and update the “normal” data base and which can be used to modify the static data with current information when it is appropriate to do so. A central issue in the development of these algorithms is provision of a satisfactory empirical foundation for both the estimation of expected travel times and estimation and prediction of travel times under abnormal conditions.

3.2 TRF Overview and Structure

The TRF system of algorithms consists of five components of which (1) the Data Base Algorithm operates once only to develop an initial data base of expected travel times, (2) the Static Profile Algorithm operates periodically to update expected travel times, and the other three components--(3) DF, (4) TT, and (5) ID (see below)--operate continuously to monitor and interpret data from probe vehicles and fixed detectors and other sources. The section describes how each of these functions are carried out.

- Base Data (BD) operates prior to the real-time operations of the other algorithms. This algorithm used network flow models and traffic flow concepts to develop initial estimates of link travel times by time of day and day type.
- Static Profile (SP) updates the base travel time data at intervals selected by the TIC manager to incorporate data from probe vehicles and fixed detectors in the continuously growing data base to obtain improved estimates of expected travel time.
- Data Fusion (DF) has two functions. It reviews data for consistency and reasonableness and screens data which is believed to contain errors and it converts fixed detector (volume and occupancy) data to estimates of link travel times.
- Travel Time (TT) Prediction uses current and expected measures of travel time to estimate travel time during the next three five-minute time intervals.
- Incident Detection (ID) compares current link traversal data from probe vehicles and volume and occupancy from fixed detectors to expected values of these measures to identify traffic flow conditions which indicate the presence of a flow restricting incident. When an incident is identified, ID generates an estimate of the expected impact on travel time and duration of that impact.

3.3 Issues in TRF Development

Three central issues arose in the development of the TRF algorithms; this section describes each of these issues, the manner in which it was addressed in *ADVANCE* and the implications for future developments of ATIS.

3.3.1 Management of a Diverse Team

The nature of an Intelligent Transportation Systems (ITS) project like *ADVANCE* requires the cooperation of professionals from different fields including transportation and traffic engineering, computer science, telecommunications, human factors, communications, navigation databases and others. In almost any phase of the project including requirement specification, design, development, testing and the production, experts in most of these fields are required to cooperate closely to achieve a satisfactory efficiency of the system.

TRF development activities were divided between UIC-UTC; for BD, SP, DF and TT; and Northwestern University; for ID; working under a common contract through the Illinois Universities Transportation Research Consortium. Further, this team coordinated with other development teams including the IVHS Strategic Business Unit of Motorola, the Electrical Engineering and Computer Science Department of the University of Illinois at Chicago (EECS-UIC) and DeLeuw, Cather and Company, the systems integration consultant. The breadth of the *ADVANCE* team ensured that the full range of development and implementation issues would be addressed at each stage in the

process.
This team structure illustrates the range of cooperation across government, private companies and universities (both public and private) which was adopted for *ADVANCE* and demonstrates that this extensive partnership can be successful and effective. However, these groups had differing styles and objectives as described briefly below; these differences created a challenge to achieve effective collaboration which needed to be addressed for the team to be effective.

The university group was responsible for conceptual design and TRF development. The primary orientation of this group was toward theoretical and applied research. The IVHS division of EECS-UIC was responsible for the implementation of the TRF algorithms as well as other aspects of the Traffic Information Center (TIC) computers. The primary orientation of this group was toward operational implementation and the need to use computer resources, data storage and processing time effectively.

The IVHS Strategic Business Unit of Motorola was responsible for development of the on-board Mobile Navigation Assistant (MNA) including both hardware and programs and the communications between the *ADVANCE* vehicles and the TIC. This group was distinct from other groups, in terms of their need to protect proprietary rights regarding products developed by the group. This placed limits on knowledge sharing concerning the internal functioning of MNA algorithms, data characteristics and the availability and use of on-board computer resources; these limitation were overcome, in part, through careful specification of data interfaces. However, the limitation on knowledge sharing resulted in residual uncertainty about the performance and effectiveness of the route selection and route diversion algorithms.

The engineers and other employees of The Illinois Department of Transportation supported by DeLeuw, Cather & Company and its sub-contractors had responsibility for overall management of and coordination among task groups as well as integration of all technical components.

A complicating issue was that these groups were located at five different sites which were as much as 20 miles apart. Advances in telecommunication technology, including the availability of Internet connections, mitigated these problems to some extent; however, frequent face-to-face meeting of all developers were required to resolve complex integration issues and ensure effective collaboration.

The System Issues Subcommittee (SIS), which included representatives of all major developers of *ADVANCE* algorithms, was formed to coordinate the development of the technical components of *ADVANCE.* The SIS was assigned responsibility to identify and resolve potential conflicts among system components, specify interfaces between algorithms, define the formats and uses of data and allocate computer processing resources to computational tasks. Despite resistance to participation in extended meetings, which required some participants to drive substantial distances, regular meetings of the SIS, chaired by the systems integration contractor, were deemed necessary to ensure good integration among all *ADVANCE* components. Effectiveness of the SIS was based on its ability to make clear-cut decisions about algorithm structures, hardware specification, data definitions and data interfaces; satisfaction of these objectives required strong leadership and clear decision making authority of the chair to be invoked if appropriate agreements could not be achieved otherwise. The effectiveness of the SIS depended on openness among all participants and the ability to make clear cut development and implementation decisions.

3.3.2 Balancing the Needs for Schedule Control and Flexibility in Response to Development Results

A central challenge in the design of the project work plan was balancing the need to have a firm schedule with fixed deadlines to meet the demonstration implementation schedule with the need for flexibility to respond to short-term changes in the development process due to the innovative character of the work. A fixed task specification and schedule has the potential to ensure availability of all the operational components for demonstration implementation as required, but can only be effective if the schedule is (a) realistic about the time needed to complete all the required tasks and (b) includes appropriate sequencing to ensure that task interdependence is adequately considered. Overly rigid planning will require repeated modification in response to unexpected developments and the unpredictable progress of a research and development effort. The *ADVANCE* project was organized with a structured development plan and schedule which were used to monitor progress and to identify and evaluate the impact of delays in any task on the overall schedule of the project. A major problem with the schedule, from the perspective of the TRF development, was the limited time available for the collection of field data prior to implementation of a fully operational system.

Collection of field data, described in the next section, was essential to the final development and validation of some of the TRF algorithms. However, since field collection of travel time data required full operation of the TIC, communications (COM), and MNA, delays in the implementation of any of these major components would limit the time available for validating, refining and testing these algorithms. Given the high cost of data collection by conventional means, the inclusion of adequate time for such data collection subsequent to full operation of necessary data collection hardware and programs is essential to the effectiveness of an ATIS development.

3.3.3 Data for Algorithm Estimation and Validation

The traffic analysis algorithms needed for application in the ADVANCE context could have been based on either algorithms developed and tested elsewhere or new algorithms specifically designed to satisfy *ADVANCE* requirements. In either case, adoption of such algorithms requires estimation or re-estimation and validation with local data. Field data collected under conditions which approximate the intended application are required to ensure effectiveness of the algorithms. Because original algorithms were proposed for development for *ADVANCE* it was necessary to collect data to refine the specification, then estimate and validate these algorithms. Further, since application of the algorithms in the *ADVANCE* context was to be based on real-time data collected from *ADVANCE*-equipped probe vehicles and fixed detectors, proper estimation and validation required that corresponding data be collected from similarly equipped vehicles and fixed detectors. Collection of data necessary to estimate and/or validate these algorithms could not be undertaken until the operational components of ***ADVANCE*** including the MNA, communications, TIC and linkage to fixed detectors were fully operational with respect to the measurement, transmission and recording of link traversal data from MNAs and fixed detectors. However, the schedule required that work on the development of the TRF algorithms be implemented prior to full operationalization of these components.

In the absence of automatic data collection, two alternatives were considered. The first, collection of data using conventional means, was rejected as excessively costly and time consuming. The second was to base initial development on simulation data generated for a portion of a major arterial within the test area and to validate and revise the algorithms with field data before field implementation. The arterial chosen was that portion of Dundee Road for which fixed detector data were to be transmitted to the TIC. The simulation was designed to correspond as closely as possible with the actual characteristics of that portion of Dundee Road. This simulation was used to generate fixed detector and probe vehicle data under a variety of traffic conditions to support initial development of the fixed detector to travel time transformation in the data fusion algorithm, the travel time prediction algorithm, and the probe vehicle and fixed detector arterial incident detection algorithms.

The plan for validation and refinement of these four algorithms with field data was set back by delays in the completion of the operational components of ***ADVANCE*** This resulted in the adoption of three different approaches for the algorithms.

(1) The fixed detector to travel time conversion algorithm validation was based on field data collected with a limited fleet of probe vehicles operating along the portion of Dundee Road on which the fixed detectors were linked to the TIC. We wished to collect a reasonable sample of travel time data that could be matched with fixed detector data for the same links and time periods and thus provide a basis for converting detector data on volume and occupancy to estimates of link travel time. The first ***ADVANCE*** vehicles equipped with an early prototype of the on-board computer were used for this purpose. The effectiveness of this data collection was limited because the on-board computers were in the early testing phase and a significant percentage of the expected data was missing due to failures in measurement, communication and/or memory card storage of the data as well as

malfunctioning of some of the fixed detectors. These limitations resulted in the collection of substantially less data than was expected and limited the effectiveness of the algorithm refinement and validation.

(2) The fixed detector incident detection algorithm validation was undertaken with field data comparable to that which would be used in a full implementation. The availability of the fixed detector data and NWCD incident data through the TIC enabled modification of the fixed detector incident detection algorithm using data similar to what would be available during full deployment; this effort was limited only by the short time period and the resulting small number of incident periods in the data.

(3) No field data were available for validation and refinement of the probe vehicle incident detection algorithm. The decision not to collect field data for this purpose was based on recognition that considerable time would be required to collect data on any reasonable number of incidents relative to the limited time available, which would not have provided adequate data to undertake any useful validation or refinement of this algorithm.

Two important lessons can be derived from the results of the algorithm developments which were undertaken and the subsequent evaluation of these algorithms. First, while the use of simulated data might be satisfactory for initial model development, simulation data alone were inadequate for full development of the required travel analysis algorithms. The disadvantage of using simulation based data is that such data may either provide a poor representation of the data patterns required for a specific purpose or suggest more precise relationships between measures than actually occur. Even in simulation packages which are carefully developed and validated and widely accepted for traffic flow simulation, not all elements of traffic flow can be fully and precisely represented.

This is demonstrated in two examples. The first is the difference observed between the fixed detector to travel time transformation in the data fusion algorithm as based first on simulation, then on subsequent field data collection. Analysis of simulation data indicated that an approximately linear relationship existed between occupancy and travel time (Sisioupiku and Rouphail, 1994). Field data collected during evaluation indicated the presence of a more complex relationship, differing for three ranges of occupancy: at low levels of occupancy, travel time is approximately constant; at moderate levels of occupancy, travel time increases in proportion to occupancy; and at high levels of occupancy, variance in travel time is so great that any relationship is questionable.

The second example concerns the incident detection algorithms. The arterial incident detection algorithm based on simulated detector data, modified with limited field data, was unsatisfactory in evaluation testing (the number of false alarms exceeded the number of detected incidents) while that based exclusively on probe vehicle incident detection was relatively successful. However, the performance of both algorithms improved substantially when the evaluation data, i.e., the first moderate sized incident-specific field data base collected under the deployed ***ADVANCE*** system, were used to refine and re-estimate these algorithms (Koppelman et al, 1996, ***ADVANCE*** Project Document #846 1.00).

The second lesson is that effective development of algorithms for implementation requires adequate time for field data collection under operational conditions, and for algorithm refinement before final implementation. The original ***ADVANCE*** development schedule included a limited amount of time for this purpose. However, the combination of delays in operational deployment of the full system and the need to meet pre-established deployment schedules limited the amount of time available for the required data collection and, in some cases (e.g., probe vehicle incident detection), no field data collection could be undertaken. The lack of adequate field data collection would have been overcome under the originally proposed full deployment during which such data collection could be undertaken automatically at no incremental cost, provided that the deployment demonstration schedule allowed for the modification of algorithms during the demonstration period. Although only substantially reduced data collection could be accomplished during the targeted deployment, which limited the opportunity for validation and refinement, the modifications which were undertaken with this more limited data base demonstrate that the targeted approach did have value.

3.4 Potential for Future Development of Real-time Traffic Analysis Algorithms

An important aspect of the ***ADVANCE*** demonstration was to clarify the potential for future development of advanced traveler information systems and their components. The results of the work undertaken to develop the various traffic analysis algorithms and their implementation indicate that (1) the computational requirements for operation of the traffic analysis algorithms in real time are reasonable; (2) the data collection, communication and storage requirements are reasonable; and (3) the algorithms for interpretation of traffic data for traffic flow characteristics are promising.

The ***ADVANCE*** design calls for the operation of each cycle of traffic analysis to be completed during each five minute period. The target deployment demonstration indicated the ability to complete all traffic analysis computation during each cycle, This result is contingent on the size of the test area network and the amount of data being processed. Clearly, the presence of thousands of probe vehicles rather than the small number deployed in ***ADVANCE*** would impact this performance, but the design of the computational structure, on a link basis, suggests that an increase in the number of probe vehicles would not have substantially undermined the performance of the TIC. Future demonstrations covering larger networks will require greater computational resources, but the ability to operate the developed algorithm structure indicates that implementation in larger networks is likely to be feasible.

The ***ADVANCE*** design calls for data collection and communication from the MNA to the TIC, interpretation of the data in the TRF component of the TIC, communication of relevant results to operating MNAs, and storage of data for future analysis. The measurement, traffic interpretation and storage capabilities were reasonably demonstrated in the ***ADVANCE*** targeted deployment. The communication requirements could not tested in this implementation as the communications requirements for the targeted deployment were very modest. Larger scale deployment would have been required to test the ability of the communication system to handle MNA to TIC link traversal reports from thousands rather than tens of probe vehicles, and TIC to MNA link traffic characteristic reports for large numbers of links for which current traffic characteristics differed from those in the static database. However, design alternatives to manage larger volumes of inbound and outbound data transmission which were developed but not fully tested indicate the potential to operate dynamically in a larger network with a larger equipped vehicle fleet.

Finally, the performance of the operational algorithms indicates the potential of both the SP updating procedure and the dynamic algorithms--DF, TT and ID--to update the static data base and use real-time data to infer the traffic characteristics of arterial roadway links. The data fusion algorithm provides a basis for estimating link travel time from fixed detector data; the travel time prediction algorithm provides improved estimates of near term travel time than those available from static data; and the incident detection algorithms indicate the potential to identify a reasonable share of roadway incidents with a much smaller number of false alarms. While all of these results are limited by the small scale and limited time period of the demonstration and by the controlled nature of the data collection, they indicate that these algorithms can be successfully refined and further developed.

4.0 SUMMARY AND CONCLUSIONS

The development and implementation of traffic related functions algorithm in ***ADVANCE*** posed significant challenges, some or all of which are likely to be faced during the development and implementation of future ATIS systems. The primary findings from the ***ADVANCE*** experience with respect to the development of algorithms to interpret traffic flow characteristics from automatically collected data are:

- The *ADVANCE* development plan included a fixed schedule and called for parallel development of the technology and the algorithms which would make the technology useful to drivers. While performing tasks simultaneously rather than sequentially enabled more rapid completion of the project than would otherwise have occurred, it also created difficulties. The most important of these for TRF development was the non-availability of actual field data for algorithm development, refinement and validation. Future development programs should allow adequate time for such data collection, with the full operating system in place, before finalization of the algorithms needed to interpret the data for traffic analysis.

- The design and implementation of ATIS projects requires collaboration among people of enormously different disciplinary backgrounds and even greater variations in institutional settings (corporate, government and university). Effective collaboration requires the institution of a coordinating organization (the System Issues Subcommittee in the case of ADVANCE) to ensure this collaboration and, when necessary, to make decisions which focus the combined resources of all partners on commonly agreed objectives.

- Development of traffic analysis algorithms should be based on field data; however, simulated data can be used as a preliminary starting point subject to validation and refinement with field data when they are available. Resource allocations for field data collection including time schedule, personnel and appropriate data collection resources should be included in the development plan.

- The TRF components of the ***ADVANCE*** project were innovative in that in neither the literature nor previously conducted demonstrations was there adequate guidance on formulating them . The development and implementation of these algorithms indicates the potential to undertake such development in other contexts. The evaluations of the component algorithms showed that they performed satisfactorily and can provide a basis for required future developments for demonstrations and implementations of ATIS systems.

APPENDIX K

TARGETED DEPLOYMENT

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TARGETED DEPLOYMENT

EXECUTIVE SUMMARY

This paper examines the issues and options considered in the decision to redirect the originally planned deployment of 3,000 in-vehicle dynamic route guidance systems to a deployment of less than 100 units. The ADVANCE success in achieving almost every one of its original goals and the wealth of data collected in this more limited effort are enumerated as a testament to the decision to implement the Targeted Deployment.

TARGETED DEPLOYMENT

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1.0 INTRODUCTION

Most of the documentation on operational field tests emphasize the complexities involved in the design, development and performance of Intelligent Transportation System (ITS) systems. Several address associated management and institutional issues. This paper will emphasize the more specific experience related to when the ***ADVANCE*** (Advanced Driver and Vehicle Advisory Navigation Concept) Project was confronted with a changed commercial and technological environment. Specifically, the decision to redirect the Project from a full deployment of thousands of vehicles to a Targeted Deployment of less than one hundred vehicles.

1.1 Acronyms and Definitions

Acronyms and definitions are contained in the *ADVANCE* System Definition Document #8020.ADV.06.

1.2 Authors

The authors of this report, involved in the development and deployment of *ADVANCE*, are as follows:

Joseph Ligas - *ADVANCE* Project Manager

Mr. Ligas was responsible for the overall coordination and implementation of *ADVANCE* He is ITS Program Manager for the Illinois Department of Transportation.

Paul Dowell - Motorola Manager for *ADVANCE*

As manager of Motorola's ADVANCE activities from 1993 through 1995, Mr. Dowel1 was responsible for design, development, manufacture, installation and maintenance of the *ADVANCE* in-vehicle navigation and route guidance system, as well as, the radio frequency communications system. He is currently Market Development Manager for Motorola.

Toni Wilbur - Federal Highway Administration

As project manager at the federal level, Ms. Wilbur was the primary national contact for *ADVANCE* during the early developmental phases and again during the Targeted Deployment. She is a Team Leader in Washington, DC.

1.3 Intended Audience

The audience for this report is intended to be those that are interested in the development and deployment of operational field test systems, such as *ADVANCE* and have a basic understanding of Advanced Traveler Information Systems (ATIS) and the overall federal operational field test program.

Researchers, designers, developers, and integrators of ITS are expected to benefit from the lessons learned from *ADVANCE*.

1.4 References

The following documents and papers would be of interest to the reader desiring further information on *ADVANCE* and its Targeted Deployment:

Documents

- Goals and Objectives Document #8010.ADV.04
- Base Data and Static Profile Evaluation Report, #8460-01
- Data Screening Evaluation Report, #8460-02
- Quality of Probe Reports Evaluation Report, #8460-03
- Travel Time Procedures and Performance of Probe and Detector Data Evaluation Report. #8460-04
- Detector Travel Time Conversion and Fusion of Probe and Detector Evaluation Report, #8460-05
- Frequency of Probe Reports Evaluation Report, #8460-06
- Relationships among Travel Times Evaluation Report, #8460-07
- Incident Detection Evaluation Report, #8461
- Familiar Driver Perspectives on ADVANCE and Future Dynamic Route guidance Systems Evaluation Report, #8462
- Dynamic Route Guidance - Yoked Driver Evaluation Report, #8463
- TIC Architecture and User Interface Evaluation Report, #8464
- Insights and Achievements of the *ADVANCE* Project -- a Compendium of White Papers by Participants and Evaluators, #8465
- Safety Evaluation, #8466

Papers

- The Evolution of *ADVANCE:* Development and Operational Test of a Probe-Based Driver Information System in an Arterial Street Network: A Progress Report. by A. Kirson, B. Smith. D. Boyce, P. Nelson, J. Hicks, J. Schofer, F. Koppelman and C. Bhat for Vehicle Navigation & Information Systems '92 in Oslo, Norway, September 1992
- Embarking on Deployment, by J. Ligas and S. Bowcott for Institute of Transportation Engineers (ITE) International Meeting in Dallas, TX, October 1994
- *ADVANCE* - Initial Deployment, by J. Ligas and S. Bowcott for the 5th Annual ITS America Meeting in Washington, D.C., March 1995
- Implementation of *ADVANCE,* by J. Ligas and S. Bowcott for the 6th Annual ITS America

Meeting in Houston, TX, April 1996

- Formal Evaluation of the ADVANCE Targeted Deployment, by C. Sariclts, P. Belella, F. Koppelman. J. Schofer & A. Sen for 6th Annual ITS America Meeting in Houston, Texas, April 1996
- The ADVANCE Transition to GCM Transportation Information Center, by J. Ligas and S. Bowcott for the 3rd ITS World Congress in Orlando ,FL, October 1996

All of the above documents are available on the Internet at the following address:

- http://ais.its-program.anl.gov/

1.5 Report Organization

This report presents the introduction in Section 1; the purpose of the report in Section 2; the methodology and results in Section 3; and the report summary in Section 4.

2.0 PURPOSE OF THIS REPORT

The purpose of this report is to document the development process and experience of the *ADVANCE* project, in particular as relates to ultimate deployment of this operational field test.

It is intended that the valuable experiences of the ADVANCE project may be useful to those currently involved or to be involved in developing and deploying future operational field tests of Intelligent Transportation Systems.

3.0 METHODOLOGY AND FINDINGS

3.1 Background

The *ADVANCE* Project was launched in 1991 as a major test of a dynamic route guidance system in the United States. The objective was to determine if motorists supplied with "real-time" guidance would be given information which would help them avoid congestion and improve the quality of their trip.

Using a combination of technologies including GPS positioning, wireless communications, CD-ROM map storage, data fusion and others, the ADVANCE Project combined real-time two-way electronic communications and CD-ROM-based database retrieval devices to provide drivers with continuously updated navigational directions.

3.2 Issues and Options

As *ADVANCE* developed, the Public/Private Partners learned much about the technologies involved. *ADVANCE* also witnessed an evolution in technology and market conditions.

When ADVANCE reached the important stage between system development and deployment, prior to installation of in-vehicle units, the public and private entities involved with ADVANCE reviewed the original scope and goals of the project depicted in Tables 1 and 2.

A.	Increase Traveler Mobility
B.	Reduce Travel Times and Costs
C.	Reduce Transportation Infrastructure Costs
D.	Increase Highway and Traffic Safety
E.	Reduce Energy Consumption
F.	Reduce Transportation Impacts on Air Quality and Noise Levels

Table 1. Policy Goals

Goals to Improve Traffic Operations	
1	Improve individual travel times by providing real time information that will allow travelers to adjust mode choice, route choice, departure time and other traveler related behavior
2	Provide navigational assistance to travelers
3	Enhance existing efforts to provide traffic information to travelers by integrating the demonstration with IDOT District One operations
4	Investigate to what extent congestion can be reduced through more effective utilization of the existing transportation network
Goals to Evaluate ITS Applications	
1	Evaluate the effectiveness of using vehicles as probes as well as other various ITS technologies
2	Evaluate the behavior and perception of travelers (including those not involved in the demonstration)
3	Identify and evaluate transition paths and costs to develop and implement an operational ITS
4	Help to determine future deployment of ITS

Table 2. Program Goals

Market conditions and available technology changed since *ADVANCE* first was proposed. Market conditions which were anticipated to support a large scale implementation of in-vehicle navigation systems did not occur as quickly as anticipated. This was apparently due to a number of factors including an inability to provide a system at a price which would be attractive. Technologies for vehicle navigation systems took longer to develop and implement than originally thought. The availability of in-vehicle navigation systems anticipated at the project inception also lagged. Much of this was likely due to the desire to develop a unit at a marketable price. Some of this was due to changes in technology and trying to adapt the systems to newer technologies which could improve performance. In any case, it was the consensus of the *ADVANCE* Steering Committee that commercial systems using dynamic information were still some time away from being available in the U.S. market place.

Given the changes described above, the *ADVANCE* Steering Committee requested a review of the deployment options. The review included the impact of deployment options on the goals of the Project. Three options were reviewed in detail:

- Controlled Wrapup - This involved stopping all further development on *ADVANCE* and documenting the results/design to date. This option was deleted from consideration as it was believed by all parties involved that there were still significant findings to be made by continuing with *ADVANCE* at minimal additional cost.

- Targeted Deployment - This option involved a reduction in the level of development with a limited deployment of vehicles. Approximately thirty project test vehicles would be used with testing being done by project staff, paid drivers and some previously recruited drivers. No in-vehicle units would be installed in private vehicles. Testing would occur over a seven month period with all testing completed by the end of December 1995. A project evaluation would be performed based on a revised set of goals and objectives. The total number of vehicles involved in supplying probe reports was less than one hundred.

- Full Deployment - *ADVANCE* would continue on its planned path with further development being done on all subsystems. The final release schedule would have been maintained and up to three thousand in-vehicle units would have been installed for a period of up to two years. A full evaluation would have been done with project testing and data collection completed by early 1998. The analysis of data and evaluation report would be completed by December 1999. The significant funding requirements, the complexities involved and the lack of an obvious transition to a wider area deployment were examined.

An analysis of these options was performed by the Project Team and the Technical Advisory Committee. The recommendation was that the Targeted Deployment option would best serve the needs of the project partners and the ITS industry as a whole. It is believed that a significant portion of the original goals and objectives could be met under a Targeted Deployment. This option allowed for limited testing of an in-vehicle dynamic route guidance system at a significantly lower budget. It expedited the sharing of state-of-the-practice results associated with the operational test. Among the items tested during Targeted Deployment were:

- Route Guidance

  Static route planner which incorporates current travel time information to select the optimal route to the destination. (Motorola Proprietary).

  Dynamic route planner which will override current route when new information indicates a faster route exists. (Motorola Proprietary).

- Dynamic Data

  IDOT Traffic Systems Center (TSC): connection to the TSC in Oak Park and process to use their information from loop detectors.

  Closed Loop Traffic Signal Systems (CLSS): connection to two masters on Dundee Rd. and ability to process information from loop detectors (volume and occupancy reported every five (5) minutes.)

  Northwest Central Dispatch (NWCD) Calls: design of connection to automated dispatch

system.
Surface Systems Inc. (SSI): automated system to provide weather information to the TIC.

- Communications
  Development and implementation of a 4,800 bps communication system in test vehicles.
  Developed and tested RF Communications 64 kbps infrastructure to allow computer to send/receive messages to/from vehicle modem and computer.

- Algorithms
  Algorithm which fuses probe and detector generated travel times into an estimate of current travel times.
  Algorithm which filters probe and loop detector information in order to predict when incident conditions exist on arterials.
  Algorithm which filters probe and loop detector information in order to predict when incident conditions exist on freeways.
  Algorithm which predicts future travel times on links based on current estimates and historical travel times.
  Algorithm which updates the current travel time database based on probe and loop detector generated travel time information by day type and time period for each link.

- Probes
  The use of model generated static profiles for initial travel time estimates.
  Estimation of link travel times from probe reports.
  The effect of probe deployment level on quality of probe reports.
  The comparison of the efficacy of probe and detector data.
  The significance and effect of the independence of probe travel time reports.

In addition. it was then possible to utilize many of the products developed in *ADVANCE* for a corridor transportation information center as part of the emerging Gary-Chicago-Milwaukee Corridor Program. The most useful are:

- TIC Hardware - all TIC hardware has been reused in the implementation of the C-TIC. One additional SUN workstation which was located at Motorola is now fully integrated in the C-TIC.

- TSC Interface - The *ADVANCE* TSC interface was fully adaptable for C-TIC implementation.

- NWCD Interface - This interface was not changed from the *ADVANCE* implementation.

There was additional code developed to automate the entry of information into the C-TIC database.

- SSI Interface - There were no modifications to the ***ADVANCE*** SSI interface for the C-TIC.

The following sections provide further background on the Targeted Deployment option and the transition to a corridor transportation information center.

3.3 Development of a Targeted Deployment Approach

A Targeted Deployment involved the equipping of project test vehicles with in-vehicle navigation units. These vehicles were used to accomplish specific tests, as noted above, of the ***ADVANCE*** concept. Data from the test vehicles were supplemented by outside sources (IDOT TSC, Dundee Road CLSS, NWCD, SSI, and IDOT Comm Center) which were being integrated into the Traffic Information Center. No units were installed in the vehicles of private drivers although short term private driver use of ***ADVANCE*** units was accomplished

With this reduced vehicle subset, testing and evaluation would be accomplished in a much shorter time frame than that for a 3,000 vehicle deployment. The proposed Targeted Deployment schedule for ***ADVANCE*** consisted of three stages:

<u>System Integration (January through June 1995)</u>

During this stage, the final versions of the four subsystems, Traffic Related Functions (TRF), Traffic Information Center (TIC). Communications (COM) and Mobile Navigation Assistant (MNA), were integrated by De Leuw, Cather and Company to function as a complete system. All development work on these subsystems were completed during this time period. with only minor calibration of parameters performed thereafter. Connections to Northwest Central Dispatch (a 911 system) and to the weather sensors provided by SSI were established during this stage.

In addition, the evaluation plan for the Targeted Deployment was also developed. This plan included detailed task descriptions, schedules, budgets and task responsibilities. Argonne National Laboratory and Booz-Allen and Hamilton served as evaluation managers to initiate work and establish a framework for the expected database. They developed detailed schedules for collection of the data during the next phase of the project.

At the completion of this stage, ***ADVANCE*** existed as a functioning system. The MNA was capable of static and dynamic route planning. The TIC and TRF had connections to the Traffic Systems Center, a closed loop traffic signal system, weather detectors, and Northwest

Central Dispatch. The TRF algorithms were capable of data fusion, limited incident detection on expressways and arterials, travel time prediction and development of new static profiles. The operator was able to monitor operations and to manually adjust parameters as well as input data as required. The operator was also able to input manually road construction and closure information as well as anecdotal information from traffic reporting services, other police organizations, etc.

System Evaluation (from June 1995 to January 1996)

This stage marked the period when *ADVANCE* as a system remained relatively stable in order to minimize the impact on data collection for evaluation purposes. Only bugs which unduly affected the system were cowected and only after an analysis was performed on their impact on system resources, system operation and system evaluation. No significant further development of ***ADVANCE*** dynamic route guidance components occurred during this stage. This decision allowed the Targeted Deployment to take place, however, it did limit the availability of some functions which would have been attractive to the consumer (e.g. “yellow pages”, street names on maps, heading up display, landmarks, ...). It also put some constraints on the amount of data which would be available on the memory card since its capabilities were not fully developed. However, the capabilities were deemed sufficient to support the Targeted Deployment. The basic system was in place which provided dynamic route guidance information using state-of-the-art design and human factors input.

The primary purpose of this stage was to have *ADVANCE* serve as a stable platform for collection of data for evaluation of the concept of dynamic route guidance. This data collection involved the use of project test vehicles with project staff, paid drivers and some previously recruited drivers. Argonne National Laboratory had the responsibility for scheduling the required resources, collecting the data, and assimilating it into a database for use by the task evaluators. As data analysis and tasks were completed, evaluation reports are being published and distributed to the community outside *ADVANCE.*

Technical documentation on *ADVANCE*, such as the System Definition Document, the Interface Control Specification, etc. were finalized and distributed. This documentation involved updating current documents to reflect changes that occurred during and following integration of the subsystems.

This stage ended on January 1, 1996, with the demonstrated use of *ADVANCE* probes in a dynamic route guidance system.

Finalize Documentation (from January 1996 thru September 1996)

Following completion of the initial onstreet use of dynamic guidance probes in *ADVANCE*, efforts concentrated on completing technical documentation and the evaluation documentation.

The technical documentation included the documents noted above as well as final documentation on the TRF algorithms (their history of development. testing performed. theory involved and recommendations for the future).

The evaluation documentation involved preparing reports on each of the tasks in the evaluation plan. The documentation included objectives, methodologies. hypotheses, analysis, and conclusions. Argonne National Laboratory had the responsibility for integrating these various reports into a final report on *ADVANCE.*

A Targeted Deployment meant that some of the project's original objectives were not fully met. Obviously, the ability to have a field test with three thousand vehicles acting as probes was not realized. However, tests of dynamic route guidance, the effect of the system on "familiar" drivers, and the operational and maintenance aspects of the system were conducted. Experience was gained with actual driver recruitment, training and vehicle installations. The ability to test the concept of probes to reflect actual traffic conditions was reduced; however deployment which emphasized corridor and sub-area concepts rather than the area-wide tests originally planned provided considerable insights. A safety evaluation remained feasible, albeit with a smaller number of drivers utilized over a shortened period of time. The statistical reliability of accident data was problematic without the full deployment. With the Targeted Deployment, the safety evaluation concentrated on the driver's use of the equipment and the measure of distraction versus more traditional forms of driver information.

There were significant benefits that resulted from or remain unchanged through the use of a Targeted Deployment. Locally, the *ADVANCE* Traffic Information Center is being transitioned to a corridor transportation information center for the Gary-Chicago-Milwaukee Priority Corridor Initiative at a quicker pace than originally envisioned The GCM area is available for serving as a test bed for other initiatives. There was the obvious fiscal savings resulting from use of a smaller number of in-vehicle units over a much shorter time frame; quicker turnaround on reports to the industry due to the shorter time frame for deployment; a limited test of the algorithms used for incident detection, travel time prediction, data fusions and static profile updates; and the ability to: conduct low cost safety studies; do some testing with "familiar" drivers; compare probes and detector loops as sources of travel times; perform a limited testing of dynamic route guidance; and continue to explore and develop the public/private partnership.

3.4 Evaluation and Documentation

In accordance with the Steering Committee's adoption of the Targeted Deployment approach, it was essential that documentation and evaluation results be provided to the ITS community as quickly as possible following the completion of the tests. To that end, all products will be available by the end of 1996. In addition to the technical reports covering system components, design, etc., a series of lessons learned and white paper reports were commissioned. They are compiled in the document entitled "Insights and Achievements of the *ADVANCE* Project, A Compendium of White Papers by Participants and Evaluators, #8465" and they include the following:

a. Contractual and Management Challenges of the *ADVANCE* Project
b. Development of the RF Subsystem for *ADVAVCE*
c. System Integration Challenges in Developing *ADVANCE*
d. Field Data Collection Activities and Experiences in Support of the Formal Evaluation of the *ADVANCE* Targeted Deployment
e. Technical Challenges in Developing *ADVANCE*
f. Estimating Environmental Effects of a Probe Vehicle-Supplemented Traffic Information System with Lessons Learned from the *ADVANCE* Targeted Deployment
g. Recruitment of Volunteer Drivers for *ADVANCE,* Summary of Procedures Followed and Lessons Learned
h. Probes and Detectors: Experiences Gained from *ADVANCE*
i. Institutional Issues
j. Implementation of Algorithms in a Real World Environment: The *ADVANCE* Experience
k. Targeted Deployment
1. *ADVANCE* Safety Evaluation Study

These papers (including this one) and many other related documents are available at the Internet address cited in Section 1.4 and should be useful to others in building an Intelligent Transportation Infrastructure.

3.5 Evolution of the *ADVANCE* Gary-Chicago-Milwaukee Corridor Transportation Information Center

With Targeted Deployment of *ADVANCE* dynamic guidance equipped vehicles came the realization that the Traffic Information Center was a resource which is the heart of information sharing efforts. The Traffic Information Center was the data gathering and processing hub of *ADVANCE* All *ADVANCE* TRF algorithms including incident detection, travel time prediction. and data fusion algorithms reside in the TIC system. The Targeted Deployment tested the system However, the wider variety of data sources which were part of *ADVANCE* continued to be available after the dynamic guidance tests were completed. With the Gary-Chicago-Milwaukee Priority Corridor Initiative solidly underway in 1995, the continued development of the TIC resource as a prototype for a three-state corridor transportation information center became extremely beneficial.

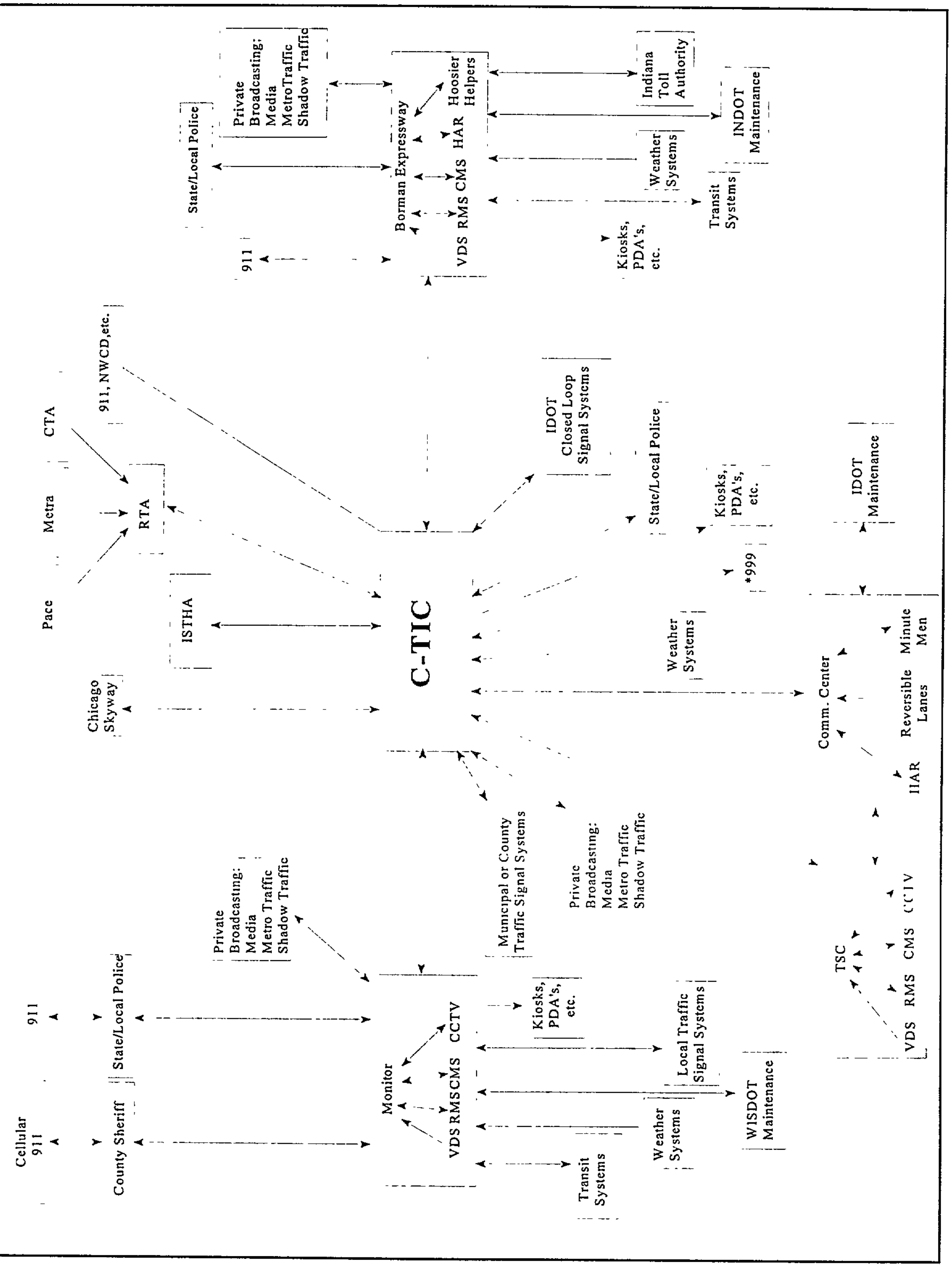
Although efforts to integrate information sources have always been envisioned in *ADVANCE,* the Targeted Deployment provided a significant opportunity to transition to the Corridor Transportation Information Center. In the period beginning January 1996, the *ADVANCE* Corridor Transportation Information Center (C-TIC) was developed to handle not only the ADVANCE database but also real-time travel information from a broad multi-state spectrum of interests. The development was done in coordination with the Gary-Chicago-Milwaukee Priority Corridor initiative and includes an advisory committee with a multi-state and multi-modal constituency.

The *ADVANCE* Corridor Transportation Information Center is expanding beyond the *ADVANCE* test area to include expressways and major arterials throughout the Gary-Chicago-Milwaukee Corridor. This Corridor Transportation Information Center includes, an electronic linkage to share information from the SSI weather information system, the Illinois DOT Traffic Systems Center, the Wisconsin MONITOR System, the Illinois DOT Communications Center, Northwest Central Dispatch, *999, selected closed loop traffic signal systems and the prototype Illinois State Toll Highway Authority AVI system. An initial geographic area including Cook, Lake and DuPage counties will be expanded to include other states or regions as the systems become more mature. Transit information, beginning with incidents and delays, will also be provided. The prototype center is envisioned to be operational late in 1996. Expansion to include information from Indiana's Borman initiative will follow, along with expansion to a broader set of public and private sector participants. The practical architecture is now being demonstrated and a full deployment scenario is being reviewed under the GCM Multi-Modal Traveler Information System effort.

The vision for the Corridor Transportation Information Center provides a system which could be accessed by a wide variety of transportation and communication interests who would share information in common formats and provide operations and safety information. Initially travel time information on selected links. construction and maintenance lane closures. and anecdotal reports of incidents will be provided on the Internet. It is anticipated that expressway travel times, lane closures and incident reports will be handled electronically for the Chicago area by the end of 1996.

The C-TIC is in the process of being further developed in accordance with the national architecture recommendations into a fully functional corridor-wide program. The prime data providers into the system are the transportation and enforcement agencies who have responsibility for the Gary-Chicago-Milwaukee area systems. Figure 1 details the relationships among the C-TIC participants. With the planned implementation, the prime beneficiaries would be the aforementioned providers

Figure 1. *ADVANCE*/Gary-Chicago-Milwaukee C-TIC Dataflow Description



plus the public who will then have access to the improved traffic and transit information. Radio and TV would also be given access. The information would be available to ITS developers and users to support not only in-vehicle guidance, but also a wide range of information concepts including personalized trip planning, providing transportation advisories through personal communication devices and general distribution through mechanisms such as kiosks and television. The C-TIC is providing significant opportunities for testing and enhancing national architecture and protocol efforts. The GCM Corridor Coalition has recently indicated that it will work with Oak Ridge National Laboratory to test the ITS Datum and Location Referencing Message Specifications. This work will serve as a national test of the ability to combine location specific information from a wide variety of geographic referencing databases. The corridor has also adopted the National Transportation Communication and Information Protocol (NTCIP) to develop systems which can be used throughout the country.

The decision to adopt a Targeted Deployment approach for *ADVANCE* was a logical step in developing and deploying ITS technology. The dynamic route guidance concept which was central to ADVANCE was tested; the infrastructure developed was transitioned to support a broader range of ITS deployments, and the multi-state corridor activities were supported and given a more central focus. The public and private participants in *ADVANCE* were provided with significant new information to continue their ITS deployment pursuits.

3.6 Major Lessons

There were many lessons from the *ADVANCE* operational test. Most are detailed in other papers. The primary lesson learned in the Targeted Deployment was the importance of a continuing. honest appraisal by the Parties involved in the Project of the viability of the operational test. Successful entities are constantly monitoring market conditions, technology, and opportunities to gauge project and product viability. *ADVANCE* was successful in following a similar course in reviewing and updating its direction based on changing conditions. The interaction among the Parties in reviewing options as the Project proceeded was a model for future efforts.

4.0 SUMMARY

Several very important conclusions and recommendations result from this review of Targeted Deployment issues encountered during *ADVANCE*. These recommendations for future ITS projects include the following:

- *ADVANCE* was able to achieve its basic goals at significant savings in time and money by adopting the Targeted Deployment strategy.

- All project management and Steering Committees should remain vigilant for changed conditions from those in existence at the inception of any large scale, long term field test.

- Redirection of efforts may well have an overall benefit, even though specific targets of development are temporarily abandoned for pursuance by future projects.

- Expediting the dissemination of current findings to other developers nationwide may be more valuable than delaying this information sharing until a more conclusive evaluation is achieved / accomplished.

APPENDIX L

ADVANCE SAFETY EVALUATION STUDY

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ADVANCE SAFETY EVALUATION STUDY

EXECUTIVE SUMMARY

The purpose of the Safety Evaluation of the *ADVANCE* Project was to assess whether drivers drive and navigate more or less safely with the MNA than without it. The project was also intended to increase the body of scientific knowledge on how drivers operate a vehicle while navigating. In order to evaluate safety, detailed data regarding driver performance was collected and analyzed. It is assumed that an empirical relationship between driving performance and safety exists, and therefore, another goal of this study was to extend the understanding of this relationship. Detailed data regarding eye glance behavior, driving performance indicators, hazard indicators and driver perceptions were collected and analyzed in order to evaluate safety.

The study examined the effects of four navigation scenarios on driving and navigation performance. The navigation scenarios were; (1) MNA with voice supplement, (2) MNA without voice supplement, (3) a paper map, and (4) a textual paper direction list. The latter two scenarios served as control conditions. In addition to the four navigation scenarios, the study examined the influence of age and experience with the MNA. The evaluation included two separate mixed factor tests. The first test was a Four Navigation Scenario x Two Age Group (25-45 and 65+) design in which navigation scenario was a within-subject variable, and age group was a between-subject variable. The second test was a Four Navigation Scenario x Two Experience Level (no prior MNA experience and some previous experience) design in which navigation scenario was a within-subject variable, and experience level was a between-subject variable. Two tests were used because an older experienced group was not available. Sixty drivers, split evenly by both age and gender, drove under each of the four different navigation conditions.

A 1995 Ford Taurus Station Wagon to which unobtrusive sensors, cameras and data-recording instrumentation had been added was used to collect the data. The instrumentation and sensor package included four hidden video cameras that provided time-stamped video images of the following: forward out-of-windshield view, lane-position view from left rear view mirror, driver's head and eyes, and the MNA display. The package also included a dual-axis accelerometer, steering potentiometer, accelerator and brake pedal sensors, laser rangefinder, audio recording, data collection computer (486 laptop), PC-VCR, and quad-multiplexer.

Four Measures of Effectiveness (MOE) of the impact of the MNA on safety were examined (see Table 1): eye glance behavior, driving performance indicators, hazard indicators, and driver perceptions. Extensive analysis of these MOE's suggests that the **MNA** system does not affect driving safety. Furthermore, no collisions occurred in over 2,000 miles driven while navigating with the MNA.

In summary, our attempt to answer the question of whether drivers drive and navigate more or less safely with the MNA than without it leads us to the conclusion that the *ADVANCE* MNA system does not affect driving safety.

ADVANCE SAFETY EVALUATION STUDY

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1.0 INTRODUCTION

Advanced Traveler Information Systems (ATIS) are intended to make travel more efficient and convenient. Efficiency is expected to be derived from the use of advanced aids for navigation, route planning, route following, the provision of real-time traffic information to drivers, and automation of real-time inputs to route planning aids. ATIS are intended to prevent drivers from becoming lost, and to assist them to plan more efficient trips and to avoid traffic incidents and congestion. The increased efficiency offered by ATIS will, in turn, reduce exposure to the roadway hazards, reducing the likelihood of experiencing a collision. ATIS are incorporated in Intelligent Transportation Systems (ITS) efforts that include research, development, and deployment of advanced transportation technologies.

The National Highway Traffic Safety Administration (NHTSA) is responsible for ensuring that the safety impacts of ITS are understood and addressed. NHTSA has three standard questions that it seeks to answer through operational testing of ITS. These are:

1. Do drivers drive more, or less, safely with the system than without it, in ways related to the system?
2. Do vehicles equipped with the system have fewer, or more, collisions than vehicles without the system?
3. If all vehicles were equipped with the system, would there be a decrease, or increase, in the total number of collisions and collision-related injuries?

The purpose of the present study was to address the first of these questions as it applies to the ADVANCE Mobile Navigation Assistant, an ATIS device fielded as a part of the ADVANCE field operational test. The study does not directly address the remaining two questions. The field operational test and safety study did not provide sufficient driving exposure or collision data to answer these questions.

1.1 Acronyms and Definitions

Advanced Traveler Information Systems (ATIS)
Intelligent Transportation Systems (ITS)
Measures of Effectiveness (MOE)
Mobile Navigation Assistant (MNA)
National Highway Traffic Safety Administration (NHTSA)
Origin Destination Pairs (O-D Pairs)
Subjective Workload Assessment Technique (SWAT)

1.2 Authors

1. Peter Sheehan, Volpe National Transportation Systems Center

Peter Sheehan is an Engineering Project Manager within the Infrastructure Systems and Technology Division at the USDOT's Volpe National Transportation Systems Center. Mr. Sheehan is involved in safety related research pertaining to ITS technology demonstration and deployment and is the task leader for the Volpe Center support to NHTSA on the *ADVANCE* project.

2. Dr. Michael Mollenhauer, University of Iowa

Michael Mollenhauer is a Research Engineer in the Human Factors Research Group at the University of Iowa's Center for Computer-Aided Design and Iowa Driving Simulator. Dr. Mollenhauer served as Co-Principal Investigator and Chicago Field Manager of the University of Iowa subcontract to SAIC and the Volpe Center for the ADVANCE Safety Evaluation. He has performed design, test and evaluation research on several ATIS systems and was a team member of the TravTek Camera Car Study. He has logged nearly 10,000 miles of on-road testing of ATIS technologies.

3. Daniel McGehee, University of Iowa

Daniel McGehee is the Director of the Human Factors Research Division at the University of Iowa's Public Policy Center. His research in transportation safety policy concentrates on the design, test and evaluation of advanced driver interfaces. McGehee served as Principal Investigator of the University of Iowa subcontract to SAIC and the Volpe Center for the *ADVANCE* safety evaluation. McGehee previously served as the Orlando Field Manager of the TravTek Camera Car study in 1993. He has logged over 15,000 miles of on-road testing of ITS technologies.

4. Dr. Thomas Dingus, Virginia Tech

Thomas Dingus is Professor of Industrial and Systems Engineering and Director of Virginia Tech's Center for Transportation Research. Professor Dingus served as Principal Investigator of the Virginia Tech subcontract to SAIC and the Volpe Center for the *ADVANCE* safety evaluation. Dr. Dingus' extensive experience in the design, test and evaluation of such ATIS devices includes the original work on the ETAK Navigator safety studies as well as serving as Principal Investigator of the TravTek Camera Car Study. He has logged over 15,000 miles of on-road research of ITS technologies.

5. Dr. Vaughan Inn-ran, Science Applications International Corporation

Vaughan Inn-ran serves as Project Manager of the Transportation Systems Division of Science Applications International Corporation. Dr. Inman is Program Manager for the Safety Evaluation of ITS technologies contract that is being performed for the Volpe National Transportation Systems Center. This work currently involves performing safety evaluations of two field operational tests. He is also the SAIC Field Evaluation Leader for the ITS Program Assessment Support program of the Joint Program Office of the USDOT. Dr. Inman serves as Lead/Principal Investigator for the TravTek Safety Evaluation, the Minnesota Guidestar Project Genesis Evaluation and the Washington State SWIFT evaluation.

1.3 Intended Audience

This paper will be of interest to ATIS/ATMS planners, designers, developers and especially those professionals involved in "field operational testing" of such systems. This paper should also be of interest to researchers involved in the safety aspects of ITS technologies.

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1.5 Report Organization

This report is divided into four sections; Introduction, Purpose, Methodology and Findings, and Summary.

2.0 PURPOSE

The purpose of the Safety Evaluation of the *ADVANCE* Project was to assess whether drivers drive and navigate more or less safely with the MNA than without it. The project was also intended to increase the body of scientific knowledge on how drivers operate a vehicle while navigating. In order to evaluate safety, detailed data regarding driving performance was collected and analyzed. It is assumed that an empirical relationship between driving performance and safety exists, and therefore, another goal of this study was to extend the understanding of this relationship. Detailed data regarding eye glance behavior, driving performance indicators, hazard indicators and driver perceptions were collected and analyzed in order to evaluate safety.

The main objectives of the safety evaluation of the *ADVANCE* Project were to:

1. Provide data and analyses of the impact of the MNA on safety.
2. Extend the ITS knowledge base with respect to vehicle navigation and in-vehicle navigation aids.
3. Support refinement of Advanced Traveler Information Systems (ATIS) design.
4. Identify potential hazards (if any) associated with use of the MNA.

3.0 METHODOLOGY AND FINDINGS

3.1 Background

Although a number of ATIS focused on navigation and traffic have been conceptualized or developed, few empirical evaluations of the safety and usability of various designs exist in the open literature. A summary of substantial efforts in this area follows.

ETAK Navigator Studies

A comprehensive effort in the examination of driver safety and navigation systems was performed under the ETAK Navigator human factors studies. These studies addressed the attention demands imposed by the ETAK Navigator upon the driver, the effectiveness and efficiency of the navigation system, and driver adaptation behavior to the navigation system. Each of these studies was performed on the road using an instrumented camera car. These studies revealed that several of the ETAK Navigator functions required a high degree of attention compared to other automotive tasks. Despite this fact, the ETAK Navigator was found to be a usable and somewhat useful device that, potentially, could be improved by conceptual and design changes. On the basis of the ETAK Navigator study results, the investigators recommended several modifications to the driver interface for future systems. These modifications included:

- Automated route selection.
- Automated zoom capability.
- Simplified information displays.
- Path feature for route planning.

Simplified information displays and automated route selection have since been included in the subsequent TravTek system and in the *ADVANCE* MNA.

TravTek Evaluation

TravTek, an ATIS system with similar functional goals to those of the MNA, was the subject a safety investigation similar to the *ADVANCE* safety evaluation. That study, the TravTek Camera Car Study, was conducted in 1993, under the sponsorship of NHTSA and the Federal Highway Administration. The purpose of the TravTek Camera Car Study was to provide a detailed evaluation of driving performance and behavior while operating the TravTek system. Although the TravTek Camera Car Study examined usability issues that went beyond the goals of the present safety study, the TravTek study shared important features with the present study.

Six navigation test configurations were used in the TravTek Camera Car Study:

- TravTek route-map display - an electronic moving map navigation display
- TravTek route-map display with supplementary voice guidance
- TravTek symbolic guidance-map display - a turn-by-turn display that presented navigation information with reduced information density relative to the route-map
- TravTek symbolic guidance-map display with supplementary voice guidance
- Paper map
- Textual direction list

Performance and usability related analyses indicated that the TravTek symbolic guidance display, with or without voice supplement, and the route-map without voice supplement were more usable for navigation than the paper map control. Specifically, drivers using these TravTek configurations required about one-half as long to reach destinations designed to be 20 minutes away than did drivers using the paper map. The route-map without voice was less usable than the other TravTek conditions or a paper direction list, when travel time was the dependent measure.

Safety related analyses indicated that the TravTek route-map without voice had the greatest negative impact on driving performance, and was the least safe of all the navigation conditions tested. However, even this negative safety indicator was substantially tempered by two other findings. First the negative impacts were not observed after drivers had used the system for two to four weeks. Second, other TravTek studies showed that when given a choice, drivers used the voice supplement and were more likely to use the symbolic guidance display than the route-map. Thus when given a choice, drivers use the display combinations that enhance safety and utility.

A primary finding of this research was that, for participating drivers (who were a mix of drivers either familiar or unfamiliar with the area), turn-by-turn guidance information (whether presented verbally, in a well-designed textual list, or by a low information density symbolic display) enhance performance, usability, and/or safety compared to alternatives that provide holistic (paper or electronic map) route information. The TravTek turn-by-turn with voice condition and a paper direction list provided the best overall driving performance. The TravTek symbolic guidance display without voice and route-map with voice also provided good overall driving performance.

Additional Navigation System Studies

Several navigation systems have been developed in Japan and Europe. As an example, Autoguide has been publicly launched as part of a European project concerned with electronic systems (PROMETHEUS). However, because many of these systems are still in their infancy, only limited usability and safety analyses have been performed. Therefore, this body of literature was of limited use in the development of the *ADVANCE* Safety Evaluation.

3.2 Methodology

Experimental Design for the *ADVANCE* Safety Evaluation

Four navigation scenarios were examined. Subjects were instructed to drive from a specific origin to a specific destination (O-D Pair) using each of the following navigation methods:

1. MNA turn-by-turn display with voice supplement
2. MNA turn-by-turn display without voice supplement
3. Paper map
4. Textual direction list.

The paper map and direction list scenarios provided baselines against which performance with the MNA was compared. In the paper map scenario, drivers were asked to use the paper map "as they normally would." The paper map scenario provided a comparison with conventional route planning and followed the prescribed O-D pair on a route selected by the driver.

The textual direction list scenario was the same as the direction list condition used in the TravTek operational test, and it offered a point of comparison between operational tests.
The evaluation included two separate mixed factor designs. The first was a Four Navigation Scenario x Two Age Group design in which navigation scenario was a within-subject variable, and age group was a between-subject variable. The second was a Four Navigation Scenario x Two Experience Level design in which navigation scenario was a within-subject variable, and experience level (i.e., whether or not there was prior exposure to MNA-assisted driving) was a between-subject variable. These designs make use of three experimental groups including young inexperienced, older inexperienced, and young experienced drivers. Due to the lack of availability of older experienced drivers, a full mixed factor design that incorporated age, experience, and navigation scenario was not possible. Therefore, it was not possible to detect interactions that might exist between age and experience. Rather, the young inexperienced drivers served as an anchor group for comparisons of the effects of age against the older experienced group, and for comparisons of the effects of experience against the younger experienced group. All drivers were recruited from the local area and thus, had a general familiarity with the Northwestern Chicago area.

Table 1 summarizes the approach of the study. The primary objective of the study was to determine the effects of MNA use on driving performance and safety. To meet the objective, three hypotheses were tested regarding driving performance, driving safety, and driver perception. For each hypothesis, the measures of effectiveness, measures of performance, data sources, and method of analysis are given.

Table 1. Summary of *ADVANCE* Safety Evaluation Approach

Objectives	Hypothesis	Measures of Effectiveness	Measures of Performance	Data Sources	Method Of Analysis
Determine effects of MNA use on driving performance and safety.	Driving performance will vary as a function of navigation scenario, driver age, and experience with the MNA.	Eye glance behavior	• Glance location mapping • Glance duration as a function of location	• Video analysis	• Descriptive Statistics • Inferential Statistics
		Driving Performance Indicators	• Speed • Speed variability • Lateral acceleration • Longitudinal acceleration • Steering wheel motion • Brake activation • Accelerator pedal motion • Trip distance • Time off route	• Video analysis • Camera Car data log	• Descriptive Statistics • Inferential Statistics
	Driving safety will vary as a function of navigation scenario, driver age, and experience with the MNA.	Hazard indicators	• Frequency of single glances > 2.5s • Turn tracking errors • Close headway (<1.6s) • Unsafe intersection behavior* • Unsafe stops* • Frequency of abrupt lateral maneuvers • Frequency of abrupt braking • Frequency and extent of lane deviations • Frequency of events with high potential for causing collisions*	• Video analysis • Camera Car data log	• Descriptive Statistics • Inferential Statistics
	Driver's perception of driving performance and safety will vary as a function of navigation scenario, driver age, and experience with the MNA.	Driver perceptions	• Perceived safety	• Questionnaire • Subjective Workload	• Descriptive Statistics • Inferential Statistics

* As interpreted by observer in vehicle

Apparatus

The vehicle used for this study was a 1995 Ford Taurus Station Wagon to which hidden sensors, cameras, and data-recording instrumentation were added. The instrumentation and sensor package included four video cameras that provided time-stamped video images of the following: forward out-of-windshield view, lane-position view from left rear view mirror, driver's head and eyes, and the MNA display. The sensor and data acquisition suite also included a dual-axis accelerometer, steering potentiometer, accelerator and brake pedal sensors, laser rangefinder, audio recording, data collection computer (486 laptop), PC-VCR, and quad-multiplexer

Procedure

An audio tape was used to brief drivers on the operation of the MNA. After listening to the taped instructions, subjects drove four, relatively short, origin-destination pairs to practice each of the four navigation scenarios. After completion of the training, subjects drove each of four longer origin-destination pairs. During each drive, the experimenter recorded pertinent information in a written experimenter log and by pressing buttons on an experimental control board designed to electronically record time-stamped information about the drive. Subjective workload ratings were obtained as the drivers passed each of five locations along each origin/destination corridor. The four origin/destination pairs were always driven in the same order. The navigation scenario assigned to an origin/destination pair was determined by a pre-defined randomization scheme such that, across drivers, each scenario was assigned to each origin/destination pair equally often. The ending of one origin/destination pair was set up to be the beginning of the next to help improve testing efficiency. A written questionnaire that explored driver's perceptions of safety was then given upon completion of the test drives

3.3 Key Assumptions and Constraints

A major assumption in this study and in particular with the hazard analysis technique is that surrogate measures are indicators of potential traffic collisions. Research into other areas of safety have shown that errors and near misses can be used as predictors of collisions (Heinrich, Peterson, and Roos, 1980). In addition, this same technique was developed and applied (Dingus et al., 1994) to driving safety assessment and it can be assumed that numbers of near misses will reflect ordinal differences in real collisions at some level. Unfortunately, an exact numerical tie between frequencies of driver errors and near misses to a resulting number of collisions has yet to be determined.

3.4 Findings

Effects of navigation condition on driver performance and safety

Differences in driver interaction with the four navigation conditions were examined. Eye glance behavior, driving performance indicators, hazard indicators and driver perceptions were used as measures to determine the nature of the interaction and its effect on safety.

Eye Glance Behavior

The paper map condition resulted in a longer mean duration of glances to the map display than any of the other conditions. The direction list and MNA navigation conditions resulted in significantly shorter glance duration. The mean duration of glances to the MNA displays is just under one second. This data is very comparable to the data collected during the TravTek Camera Car Study where the glance duration for the turn-by-turn displays was also just under one second. Glance durations found for the paper map condition were on the order of 0.6 to 0.8 seconds longer than the glance conditions to all other navigation conditions. This difference in time is fairly sizable given the dynamic nature of the roadway environment. Many things can happen and long distances can be traveled in 0.6 to 0.8 seconds, indicating that there might be times when this difference is enough to present a potential compromise to driving safety.

In terms of relative safety, the MNA conditions appear to result in display glances that are shorter in duration than those for the paper map, and are no different that those for the direction list. Therefore, there does not appear to be anything about the MNA display that results in longer glances away from the roadway and that could diminish safety. Also, all glances to the display greater than 2.5 seconds in duration were recorded and there were no differences found between the four navigation conditions, which further supports this conclusion.

The paper map resulted in a lower proportion of glances to the map display and a higher proportion of glances to the roadway than any of the other navigation conditions. The direction list resulted in the next largest proportion of glance time to the direction list display and next smallest proportion to the roadway with the MNA resulting in the highest proportion of glances to the MNA display and the smallest proportion to the roadway.

The subjects looked at the map for longer periods of time, but they did so much less frequently than with the other navigation conditions. Conversely, the subjects looked at the MNA for shorter periods of time, but they did so much more frequently than with the other navigation conditions. There are several possible reasons for this. First, the MNA displays navigation information one turn at a time, requiring the subject to look at the display at least once after each turn is complete to obtain the information about the next turn. The resulting need to monitor the display is probably what caused the MNA conditions to result in higher proportions of glances to the display and lower proportions to the roadway. Second, many of the subjects chose to bring the vehicle to a complete stop before attempting to read the map. Only glances that occurred while the vehicle was moving were included in this analysis, so those glances would not be accounted for here. Last, a novelty effect was likely present. Subjects tend to devote "spare" capacity to a novel device.

In terms of relative safety the MNA conditions appear to result in larger proportion of glance time to the display than the other navigation conditions. While this result appears to diminish safety, the quickness with which each glance to the MNA occurs, the low density of information obtained during the glances and the existence of a novelty effect reduces the negative impact on safety.

Driving Performance Indicators

Looking across all driving performance indicators, the results indicate that the MNA does not appear to affect safety. It should be noted that the test was designed to represent a "worst case scenario". That is, two-thirds of the drivers had no previous experience with the MNA device, one-third were over the age of 65, and training and practice before being tested with the system were not extensive. Yet, even under worst case conditions, the performance measures did not suggest negative impacts on safety as a result of the requirement to use the MNA. On the contrary, there were several performance measures that suggest that the MNA has the potential to help improve driving safety (i.e., time off route, rate of steering wheel inputs and accelerator pedal inputs)

Hazard Indicators

Results of the Hazard Analysis indicates that there is a lack of hazard differences between navigation scenarios. Overall lack of differences held true for analyses of several characteristics of the errors such as severity, environmental proximity, and general risk categorization. The general risk categorization analysis showed that the older drivers committed more undesirable errors in the two MNA scenarios than in the two control scenarios. This difference did not hold true when looking at errors of an unacceptable nature, which is a higher risk category.

Even though there was considerable variability in the numbers of errors committed by the individual subjects, statistical differences were found between each navigation condition collapsed across all classifications and types of errors. The MNA without auditory condition resulted in fewer driver errors than the paper map navigation condition. The MNA with auditory and direction list conditions were not found to be different from any of the other conditions. This is an interesting result because it is typically hypothesized that the addition of auditory information can help relieve drivers of some of the demands of driving with a navigation system, thereby reducing the likelihood of driver errors. An evaluation of the TravTek device demonstrated this in that driver performance and safety (with TravTek's route map and turn-by-turn displays) were enhanced through the use of supplemental auditory information (Dingus et al,, 1994). The hypothesized benefits of adding auditory information were not detected during this evaluation, as supported by the lack of differences between MNA configurations across any of the safety-related measures. Anecdotally, the timing of message delivery appears to have contributed to driver error. Also, the vocabulary of the *ADVANCE* MNA is smaller than that of the TravTek system.

Driver Perceptions

Driver Perception data indicated that in general, the drivers rated the MNA very positively. The MNA with or without voice supplement was typically rated better than, sometimes the same, but never worse than the paper map or direction list. Between the MNA configurations, the MNA with voice supplement was rated just as well if not better than the MNA without voice supplement. Subject responses to the direct question of how often they felt safe with the MNA scenarios, yielded greater expressions of feeling safe than with the paper map condition. When asked to rank order the four navigation conditions from one to four based on their relative safety, drivers ranked the MNA without voice supplement as the safest, the MNA with voice supplement second safest, and paper map and direction list tied for fourth.

Subjective workload measures were collected using a three-dimensional verbal response method similar to the Subjective Workload Assessment Technique (Reid *et.al., 1982)*. This method of workload analysis did not detect any statistically reliable workload differences as a function of navigation scenarios, age groups, or experience levels. The failure to detect workload differences may have been because the method of measurement is not very sensitive, or because there really are no differences in workload. In either case, the lack of differences is consistent with the objective performance results where few differences were detected, and none of the detected differences were large.

Effects of experience on driver performance and safety

Driver experience with the MNA did have some impact on eye glance behavior. The navigation condition and experience level interaction for the proportion of glance time to the navigation display showed an effect where the experienced drivers showed no difference in the proportion of glance time to the navigation display, while the inexperienced subjects spent a greater proportion of their glance time looking at the MNA without auditory information than for the MNA with auditory information. This suggests that with additional experience, subjects learn to use the visual portion of the MNA well enough that the supplemental auditory information has no impact on the proportion of time looking at the display. While subjects are inexperienced, the addition of the auditory information results in a reduction in the proportion of time spent looking at the display. The same effect based on experience can be seen for the number of glances greater than 2.5 seconds. Thus, when the driver is inexperienced, the auditory information may help mitigate the visual attention demands of the system, resulting in less time spent looking at the display, and fewer occurrences of inherently dangerous glances, which could help reduce the potential for a crash.

There was an unexpected lack of error difference for subjects in the different experience groups. Before experimentation, it was assumed that the experienced drivers would commit fewer errors than the inexperienced drivers when using the MNA conditions. There are several possible explanations for this result. First, there was a gap of about five to six months between when the experienced group acquired their experience and when they drove in the experiment. Second, the two weeks of additional experience might not have been long enough to realize the advantages of greater exposure to the system. Finally, it is possible in this case that additional experience with the MNA device may not have had an impact on safety-related driving errors.

Effects of age on driver performance and safety

No significant differences in eye glance behavior were found for driver age. This is itself a positive result because it is often hypothesized that older age drivers might not have the cognitive and perceptual capacities to use technological advancements such as the MNA. The glance duration measure suggests no safety difference between young and old associated with the use of the MNA.

There was an age-related interaction found where the younger subjects showed no differences in driving performance between navigation conditions, but the older subjects did. The older, inexperienced drivers took longer to complete the drive when using the paper map when compared to the direction list. This difference was most likely caused by the fact that the older drivers spent more time off route with the paper map than with the direction list. Therefore, any difference in total time required to complete the drive between navigation conditions for older drivers is correlated with and probably due to the amount of time spent off route. The MNA conditions were not different from the paper map or direction list conditions for either total time to complete the drive or total time spent off route, so it is reasonable to say that there are no differences in safety between the MNA and baseline conditions in terms of roadway exposure or situations of confusion such as being off route.

There were statistically significant age-related effects where the older subjects committed more errors than their younger counterparts with each navigation condition tested; this is true of all errors combined and navigation-related errors. The main effects are most likely due to the age-related deficits in perception, cognition, and general driving abilities. There were no differences in errors committed with respect to navigation conditions.

4.0 SUMMARY

Overall Safety Impact

The primary objective of this project was to determine whether drivers drive more or less safely with the *ADVANCE* MNA than without it, in ways related to the system. Because the MNA is a navigation guidance system, it was compared with other conventional methods of navigation, Based on the extensive data gathered in this research, the *ADVANCE* MNA system does not affect driving safety when compared to conventional navigation methods (i.e., paper map, direction list).

Eye glance data and especially mean duration of eye glances to the navigation device proved to strongly support this result. Changes in driver eye glance behavior due to the use of a navigation method provides evidence of potential impacts on safety. Most of the information we use while driving is gathered by scanning the roadway environment. The positioning of the vehicle in a lane, monitoring traffic control signals, and locating and avoiding potential hazards are all important visually-oriented tasks. Any change in the way we scan the roadway environment brought about by the use of a navigation method can have a potentially negative effect on safety. Obviously, the more time the driver's eyes are off the roadway, the greater the probability that the driver will miss an important cue. The paper map condition resulted in a longer mean duration of glances to the display than any of the other conditions. The greater complexity of the paper map with its small font and dense quantities of information surely contributed to this finding. The direction list and MNA conditions were designed to provide only those instructions necessary to complete the route, whereas the paper map contained all of the roadways in the testing area. The task of reading the map might also be longer due to the fact that the driver must first locate his or her current position and then determine the next maneuver to get to the destination. The direction list had the turns listed step by step, while the MNA conditions listed only the next turn on the route, greatly simplifying the display complexity.

The mean duration of glances to the MNA displays is just under one second. This data is very comparable to the data collected during the TravTek Camera Car Study where the glance length for the turn-by-turn displays was also just under one second. The additional glance duration that was measured between the paper map condition and all other conditions in this study is on the order of about 0.6 to 0.8 seconds. This difference in time is fairly sizable given the dynamic nature of the roadway environment. Glance durations found for the paper map condition were on the order of 0.6 to 0.8 seconds longer than the glance conditions to all other navigation conditions.. It should also be noted that the subjects were given an option to make handwritten notes to use during their drive with the paper map. Many of the subjects exercised this option, and glances to their notes were counted as glances to the navigation display. What this really means is that the glances to the notes were probably shorter than they would have been to an actual road map. If the option to use notes had not been given, the mean duration of glance to the paper map would probably have been longer. In terms of relative safety, the MNA conditions appear to result in display glances that are shorter in duration than those for the paper map, and are no different that those for the direction list. Therefore, there does not appear to be anything about the MNA display that results in longer glances away from the roadway that could be a hazard to safety

Subject responses to the direct question of how often they felt safe while driving with the navigation conditions indicate that the MNA conditions provided greater feelings of safety than the paper map condition. This was also true of the question that asked subjects to rank order the four navigation conditions from one to four based on their relative safety. The rankings listed the MNA without auditory as the safest, and MNA with auditory as the second safest, and there were no statistical differences between the paper map and direction list conditions, which were both ranked below the MNA conditions.

In a question about how distracted the drivers felt they were while using the system, subjects rated both the MNA conditions as less distracting than the baseline paper map and direction list conditions. The same results were found for a question that asked how comfortable subjects were with the navigation methods. Again, the MNA conditions were both rated such that subjects almost always felt comfortable using them. Other questions tried to identify feelings of safety through less direct questions. When asked to rate if they felt they kept their eyes on the road more or less with the condition than during their normal driving, the mean responses indicate that drivers felt they kept their eyes on the road more with the MNA with voice than with the paper map and direction list conditions. Drivers also felt that they were more aware of their surroundings when using the MNA with auditory than with any other condition. The MNA without auditory was also rated better than the paper map, but not the direction list. Clearly, the subjective ratings indicate that subjects had a positive experience with the MNA conditions and felt relatively more safe when using them than the baseline conditions.

The data indicates that the turn-by-turn navigation method used in the MNA and the TravTek interface is an effective method of information presentation. In addition, by allowing more efficient navigation and less off route or lost time, such systems can potentially reduce a driver’s exposure, thereby reducing overall crash rates.

In summary, our attempt to answer the question of whether drivers drive and navigate more or less safely with the MNA than without it leads us to the conclusion that the ADVANCE MNA system does not affect driving safety.

Lessons Learned for Future ATIS Designers

Because this project examined the relative safety of the MNA to conventional navigation methods, the lessons learned from this project were obtained from the driving performance indicators, safety-related errors, and subjective assessments of the drivers. Based on the data reviewed in this report, the lessons learned from this project for improving future ATIS navigation display designs are most strongly linked to the voice supplement of the MNA. Future ATIS navigation system designers should explore the effects of voice message content and timing of message delivery and their relationship to driving performance, safety, and driver preference. More context-specific voice information may provide drivers with increased confidence and situation awareness, and increase safety. As the computing power for in-vehicle navigation technology increases, so will the number of sophisticated real-time options.

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APPENDIXM

ADVANCE

Advanced Driver and Vehicle
Advisory Navigation Concept

GIossary of ITS and Related Terms
Used in These and Other ***ADVANCE*** Reports

DISCLAIMER

This report was prepared by a contractor for
Argonne National Laboratory
and is published as it was received.

This appendix contains a brief description of *ADVANCE*- and ITS-related terms and acronyms that can be found throughout the *ADVANCE* documents.

Definitions

AAA - American Automobile Association. AAA is a Member of the *ADVANCE* Project.

Acceptance Criteria - The criteria a system or component must satisfy in order to be accepted by a user, customer, or other authorized entity. (See IEEE Std 610.12-1990.)

Acceptance Testing - Formal testing conducted to determine whether or not a system satisfies its acceptance criteria and to determine whether or not to accept the system. (See IEEE Std 1012-1986[12].)

Address - A specification of a location consisting of a number, fully qualified road name, city and state or province.

Address Book - A collection of locations, maintained in alphabetical order, associated with a registered driver. Each location has a user-specified identifier (e.g., grandma's house) which can be used to refer to the location for inclusion into trip plans.

Advanced Driver Information Systems (ADIS) - Vehicle features that assist the driver with the planning, perception, analysis, and decision-making.

***ADVANCE* Link ID** - The *ADVANCE* Link ID consists of two (2) twenty-four (24) bit SIF segment IDS. Each SIF segment ID is in fact a twenty-three (23) bit ID. The 24th bit is a direction bit as SIF segments are not directional. The two segments must consist of an approach segment followed by a turning movement segment. The turning movement includes the straight through movement.

***ADVANCE* Network Representation (ANR)** - This is an ASCII file generated by the TRF group that combines information from the CATS file, field observations, and the MIF file to describe the test area. The file is indexed by link number (both the ANR link number and the *ADVANCE* link ID.) The links are described by their physical characteristics and include the link length, speed limit, rail road crossings, lane movements, turning restrictions, and street name as a minimum. This file is generated off-line (not on the TIC computer.) Some of the data in this file will come from the Network Flow Model.

Advanced Public Transportation Systems (APTS) - Application of ITS technology (electronic, computer and telecommunications) to public transportation services in order to improve utilization and performance of these services.

Advanced Traffic Management Systems (ATMS) - Regional systems aimed at optimizing traffic flow for a set of roads or the entire region. Elements include sensors to monitor traffic flow for a set of roads or the entire region, centrally programmable traffic lights, automated highway signs, computers and telecommunications technology.

Advanced Traveler Information Systems (ATIS) - A collection of developed technologies aimed at providing real time information about traffic conditions, schedules and routes.

Algorithm - (1) A finite set of well-defined rules for solution of a problem in a finite number of steps; for example, a complete specification of a sequence of arithmetic operations for evaluating sine x to a given precision. (2) Any sequence of operations for performing a specific task. (See IEEE Std 610.12-1990.)

Algorithm Analysis - The examination of an algorithm to determine its correctness with respect to its intended use, to determine its operational characteristics, or to understand it more fully in order to modify, simplify, or improve it.

Alias - (1) An additional name for an item (2) An alternate label. For example a label and one or more aliases may be used to refer to the same data element or point in a computer program.

Arterial Roadway - See "Functional Classification."

Artificial Intelligence (AI) - A computer software programming technique in which a computer learns from past experience, allowing it to make more intelligent decisions with greater program use.

Attribute Data base - This data base will be generated off-line and contain the data elements from the ANR that are required by on-line data fusion, travel time prediction and incident detection. This data base will be updated whenever there is sufficient change in the network topology or when a new MIF is generated. Once updated, the data base is then given to UIC-EECS to be included in the TIC data base.

Audit - An independent examination of a work product or set of work products to assess compliance with specifications, standards, contractual agreements, or other criteria. (See IEEE Std 610.12-1990.)

Automatic Incident Detection - The detection at the TIC of activities on the roadway which are not the norm for that particular time, day, week or month. This detection is to be done automatically with no input required from the operator. The detection shall be based on input from probes and such other data as may be available. (Also see "Incident Detection.")

Automatic Vehicle Identification (AVI) - A system that combines an on-board transponder with roadside receivers to automate identification of vehicles for purposes such as electronic toll collection and stolen vehicle recovery.

Automatic Vehicle Locating and Monitoring (AVLM) - System designed to automatically manage bus transit system using on-board bus electronics and radio communications technology. The central computer is equipped to record and provide real time schedule and other operational information.

Automatic Vehicle Location (AVL) - A computerized system that tracks the current location of vehicles in a fleet. It is used to assist in applications such as dispatching.

AutoscopeTM - A system that uses a video camera and computer software to analyze roadway images and extract traffic flow information, as was developed by the University of Minnesota.

Backward Link - The link which the vehicle has just previously traversed.

Base Road Name - The name of a roadway stripped of its road type (St, Ave, Rd, Blvd, etc...) and any affixes.

Baud - Unit of signal frequency in signals per second. Not synonymous with bits per second since signals can represent more than one bit. Baud equals bits per second only when the signal represents a single bit.

Block Diagram - A diagram of a system, computer, or device in which the principal parts are represented by suitably annotated geometrical figures to show both the functions of the parts and their functional relationships. (See IEEE Std 610.12-1990.)

Calendar Day - Consecutive days, including Saturday, Sunday and Holidays.

Castle Rock Consultants (CRC) - CRC Corporation Limited. Subconsultants to De Leuw, Cather & Company.

Chicago Area Transportation Study (CATS) - The electronic network description file supplied by CATS. This file is used by the TRF group along with the MIF file from Motorola to build the ANR file.

Cellular *999 - Motorist information and retrieval service operated by the Illinois Tollway Authority to obtain traffic condition information from motorists with cellular phones.

Channel Saturation - The outbound channel will be saturated when COM. 1 continuously transmits at an RF data rate of 4800 baud.

Client - (1) One of two components comprising Sun's Network File System (NFS.) The system includes a networked microprocessor-based host (called the "Server") that handles the bulk of the processing, and one and more desktop computers (called the "Clients") providing the interface but little of the processing. (2) A software component which uses a defined interface to access the specialized features of a server. (Also see “Server” and “Client-Server.“)

Client-Server - A computer architecture in which the tasks required to execute an application are distributed among computer components according to each component’s suitability to perform the task.

Closed Loop Signal System (CLSS) - A traffic signal control system which has two-way communication between a master traffic controller and a remote location, usually the traffic engineer’s office. The master traffic controller also communicates with numerous local traffic signal controllers. The maximum number of local traffic controllers in the system depends on the manufacturer.

Closed Loop Signal System Connection - The connection from the master of a closed loop traffic signal system to the TIC.

Collector Road - See “Functional Classification.”

Collision - Simultaneously transmitted MNA messages and detection (when multiple RF base stations are used) of duplicate received messages.

Collision Sense Multiple Access (CSMA) - The protocol used by the MNAs to arbitrate access to the RF channel.

COM Center - See “Communications Center.”

Communications - The term “communications” as used throughout the *ADVANCE* project, refers to communications via the RF communications system.

Communications Center - The IDOT District 1 Operations and Communications Center. The Center is the operations hub of the District with the primary responsibility of “calling out” the appropriate personnel and coordinating their actions by using up-to-the-minute information from various agencies. The Center operates an extensive highway information system serving major interstates, arterials and secondary roads maintained by IDOT District 1. The system includes Highway Advisory Radio, handling of incident reports and dispatch for IDOT maintenance vehicles, including Minutemen courtesy patrol and snow removal.

Communications Center Connection - The connection from the IDOT Communications Center to the TIC to allow for transfer to and from the TIC of information regarding incidents.

Component - One of the parts that make up a system. A component may be hardware or software and may be subdivided into other components. (See IEEE Std 610.12-1990.)

Conceptual Design - An overview of the *ADVANCE* system. Explains philosophy and terminology used to collect, analyze and communicate dynamic traffic information. A System Architecture is given that outlines basic functionality in terms of the Traffic Information Center, an RF Communications Infrastructure, and a population of Mobile Navigation Assistant units and Traffic Related Functions.

Correctness - (1) The degree to which a system or component is free from faults in its specification, design, and implementation. (2) The degree to which software, documentation, or other items meet specific requirements. (3) The degree to which software, documentation, or other items meet user needs and expectations whether specified or not. (See IEEE Std 610.12- 1990.)

Current Driver - The registered driver whose set of preferences, detours, and trips are currently being used by the system for navigation.

Data - (1) A representation of facts, concepts, or instructions in a manner suitable for communication, interpretation, or processing by human or by automatic means. (2) Sometimes used as a synonym for documentation. (See IEEE Std 610.12-1990.)

Data Dictionary - (1) A collection of the names of all data items used in a software system, together with relevant properties of those items; for example, length of data item, representation, etc. (2) A set of definitions of data flows, data elements, files, data bases, and processes referred to in a leveled data flow diagram set.

Data Flow Diagram - A diagram that depicts data sources, data sinks, data storage, and processes performed on data as nodes, and logical flow of data as links between the nodes. (See IEEE Std 610.12-1990.)

Data Fusion (DF) - A TRF algorithm on the TIC. Data Fusion acts as an intermediary between external components and other TRF components. It will screen data received from CLSS and probe vehicles and aggregate this with all other on-line data to estimate link travel times for the last five (5) minute interval.

Data Structure - A physical or logical relationship among data elements, designed to support specific data manipulation functions. (See IEEE Std 610.12-1990.)

Data base - A collection of interrelated data stored together in one or more computerized files. (See IEEE Std 610.12-1990.)

Day - Midnight to midnight the following night.

Dead-Reckoning - Dead-reckoning is a technique that calculates the current location of a vehicle by measuring the distance and direction that the vehicle has traveled since leaving a known starting point.

De Leuw, Cather & Company (DCCO) - De Leuw, Cather & Company is providing system engineering services to IDOT and is responsible for system integration and testing on the *ADVANCE* project.

Deployment Phase - The phase in which project and publicly owned vehicles will be outfitted with MNAs. Utilitizes tested version of Release 1.5. See Development Phase for a description of the first phase of the project.

Design Requirement - A requirement that specifies or constrains the design of a system or system component. (See IEEE Std 610.12-1990.)

Design Specification - A document that describes the design of a system or component. Typical contents include system ‘or component architecture, control logic, data structures, input/output formats, interface descriptions and algorithms. (See IEEE Std 610.12- 1990.)

Destination - A location representing a travel objective.

Detailed Design - (1) The process of refining and expanding the preliminary design of a system or component to the extent that the design is sufficiently complete to be implemented. (2) The result of the process in (1). (See IEEE Std 610.12-1990.)

Detour - A set of roads or portions of roads whose use is discouraged (exclusion) when selecting a route.

Development Phase - Release 0,0.5, and 1.0 of the project. During this phase, *ADVANCE* project vehicles will be used with MNAs. See Deployment Phase for a description of the next phase of the project.

Differential Correction - A technique for overcoming GPS position determination errors. A GPS receiver is placed at a precisely identified control location. The difference between the indicated GPS position and the actual position is calculated. Correction information is then broadcast for other GPS systems to use in making their position determinations.

Document - (1) A medium, and the information recorded on it, that generally has permanence and can be read by a person or machine. (2) To create a document as in (1). (See IEEE Std 610.12-1990.)

Documentation Work Plan - A subset of the Project Management Plan. It is intended to identify those documents necessary to provide technical and procedural guidelines for the design, operation and testing of *ADVANCE.*

Dual Incidence Matrix Encoded (DIME) files - Computer-based map files created under contract to the U.S. Census Bureau and used for the 1980 census. The comparable files for the 1990 census are called the TIGER files.

Dynamic Profile - Current information sent from the TIC to the MNAs indicating a travel time revision for a link.

Dynamic Route Guidance System (DRGS) - Route guidance system in which the route proposed is updated based on real time traffic information.

Dynamic Route Planning - The process in the Mobile Navigation Assistant (as well as at the TIC for testing purposes) that uses data from a variety of real time as well as historical sources to determine a recommended travel route. The algorithm is the same as that used in static route planning.

Dynamic Travel Time - Travel time information based upon current information including probe vehicles, IDOT TSC, “999, closed loop signal information, etc.

Electronic Toll and Traffic Management (ETTM) - Uses AVI to electronically collect tolls, enabling vehicles to pay tolls with less delay at tollbooths.

Electronic Toll Collection (ETC) - Advanced toll collection systems using transponder/toll plaza telecommunications devices such as AVI or ETTM systems. Goals of using ETC include increased toll lane throughput. Encompasses both read only and read/write systems and uses short range communications between vehicles roadside.

Error - The difference between a computed, observed, or measured value or condition and the true, specified, or theoretically correct value or condition. Systematic Error: A constant error or one that varies in a predictable manner (e.g., equipment misalignment.) Random Error: An error that varies in a random fashion (e.g., an error resulting from radio static.) (See IEEE Std 610.12-1990.)

Escape Clausing - A method of processing data in which groups or sequences of data are analyzed to determine whether or not the data shall continue with the transmission process.

Ethernet - A *de facto* standard LAN using coaxial cables and CSMA/CD (Carrier Sense Multiple Access/Carrier Detect.) Similar to an IEEE 802.3 LAN.

Evaluation Plan - Provides a comprehensive set of procedures to evaluate the effectiveness of the *ADVANCE* ITS approach. Intended to guide the evaluation of results after the system testing activities have been concluded.

Expressway - See "Functional Classification - freeway."

External Interface - The software and hardware required to provide communications between a system external to *ADVANCE* and to and from one of the subsystems of *ADVANCE* (i.e., MNA, TIC, COM, TRF, AAA.)

Failure - The inability of a system or component to perform its required functions within specified performance requirements. (See IEEE Std 610.12-1990.)

Fast-Trac - Oakland County, Michigan field test of ATMS and ATIS.

Fault - (1) A defect in a hardware device or component; for example, a short circuit or broken wire. (2) An incorrect step, process, or data definition in a computer program. (See IEEE Std 610.12-1990.)

Federal Highway Administration (FHWA) - One of the founding Parties. FHWA is responsible for the overall evaluation of the *ADVANCE* project.

File Transfer Protocol (FTP) - A means of transmitting data files electronically between two modems by breaking each file into smaller "packets," comprised of a fixed number of bits, which are reassembled at the receiving end.

Firmware - The combination of a hardware device and computer instructions and data that reside as read-only software on that device. (See IEEE Std 610.12-1990.)

Flowchart - A control flow diagram in which suitably annotated geometrical figures are used to represent operations, data, or equipment, and are now are used to indicate the sequential flow from one to another. (See IEEE Std 610.12-1990.)

Forward Link - One of the n links on which the vehicle is currently traveling.

Freeway - See "Functional Classification."

Full Duplex - Simultaneous two-way independent transmission in both directions. Also referred to as simply "duplex."

Functional Classification - Roadways are grouped into the following categories for the purpose of design, funding and access:

Local. Local roads comprise all facilities not included in one of the higher classifications. They permit direct access to residential properties, abutting lands and connection to higher classifications of roadways. They offer the lowest mobility and usually contain no bus routes. Through traffic movement usually is deliberately discouraged.

Collector. A collector street provides both land access service and traffic circulation within residential neighborhoods and commercial and industrial areas. It differs from the arterial system in that facilities on the collector system may penetrate residential neighborhoods distributing trips from the arterials through the area to their ultimate destination.

Arterial. An arterial serves the major centers of activity, high traffic volume corridors and supplements freeways for long trip desires. Arterials include but are not restricted to partially controlled access facilities. Arterials provide for a high degree of mobility, while providing access to commercial and industrial areas. Ideally, an arterial does not penetrate residential neighborhoods.

Freeway. A freeway has full control of access where the right of owners or occupants of abutting land to access a highway is fully or partially controlled by public authority. Full control of access means that the authority to control access is exercised to give preference to through traffic by providing access connections with selected public roads only and by prohibiting crossings at grade or direct private driveway connections. Freeways may be toll or non-toll facilities. In the State of Illinois, “expressway” is the legal term for what is the national definition of “freeway.”

Functional Design - (1) The process of defining the working relationships among the components of a system. (2) The result of the process in (1). (See IEEE Std 610.12-1990.)

Functional Requirement - A requirement that specifies a function that a system or system component must be able to perform. (See IEEE Std 610.12-1990.)

Functional Specification - A document that specifies the functions that a system or component must perform. Often a part of the requirements specification. (See IEEE Std 610.12- 1990.)

General and Detail Design Specification - Provides increased detail describing the modular and functional structure of the project. Outlines the interfaces to the system environment for use during the programming phase of the project and serves as the controlling technical baseline for coordination with the other groups working on *ADVANCE.*

Geographic Information System (GIS) - A computerized data management system designed to capture, store, retrieve, analyze, and report geographic and demographic information.

Global Positioning System (GPS) - A government-owned system of 24 earth-orbiting satellites that transmit data to ground-based receivers. GPS provides extremely accurate latitude and longitude ground position in WGS-84 coordinates. However, for U.S. strategic defense reasons, deliberate error (called selective availability) is introduced into the code that is provided for civilian users.

Half Duplex - A circuit designed for two-way transmission but not both directions simultaneously.

High Occupancy Vehicle (HOV) - Any vehicle, bus, van, or car with multiple riders. An HOV lane refers to a roadway lane reserved for use by HOV's

Highway - 1) A general name referring to roadways of various functional and design classification types including freeways, expressways, arterials and collectors. 2) A legal term describing any public way used for vehicular travel. The term "highway" includes rights-of-way, bridges, drainage structures, signs, guard rails, protective structures and all other structures and apparatus necessary for vehicular traffic.

Highway Advisory Radio (HAR) - A traffic information broadcasting system used in the U.S. Drivers are alerted to tune their car radios to a specific channel in order to receive transmitted information.

Highway Users Federation for Safety and Mobility (HUFSAM) - A Washington-based coalition of 400 corporate and association members (plus some 2,000 individual members) with affiliated groups in each state and 14 regional offices around the country. Its main goal is to serve the common interests of business and industry in advancing highway transportation safety and efficiency. HUFSAM was instrumental in the formation of ITS AMERICA. The Highway/Vehicle Technology Committee of HUFSAM, composed of representatives from major U.S. transportation companies, is charged with identifying the value of ITS and defining how such systems can be effectively utilized.

Historical Travel Time Data - Roadway travel times originally based on CATS or other previous studies.

Hypertext Transfer Protocol (HTTP) - A means of electronically accessing via telecommunications lines remotely-stored data files encoded in hypertext markup language, the language recognized by most browsers written for the Internet.

IBI Group (IBI) - Subconsultants to De Leuw, Cather & Company.

Illinois Department of Transportation (IDOT) - One of the founding Parties. IDOT is responsible for providing project management for *ADVANCE* and for operating the TIC.

Illinois Universities Transportation Research Consortium (IUTRC) - IUTRC is a non-profit corporation owned by Northwestern University, the University of Illinois at Chicago, the University of Illinois at Urbana-Champaign and the Illinois Institute of Technology.

Inbound (RF communications message) - A communications message transmitted by a probe vehicle to the TIC.

Incident Detection - The detection at the TIC of activities on the roadway that significantly reduce the capacity of the roadway from the expected capacity at a particular time. The detection may be based on input from probes, fixed detectors, anecdotal sources, and such other data as may be available.

Intelligent Transportation Systems (ITS) - Application of electronic computer and telecommunications technology to add efficiency to monitor vehicle use and capacity of existing roadways. ITS goals include alleviating traffic congestion, reducing accidents, using energy more efficiently, reducing emissions, and increasing ridership and bus transit.

Interchange Link - A simple link formed by a pair of adjacent simple segments, with at least one of the simple segments being an interchange segment.

Interchange Segment - A simple segment specified to represent the physical nature of an interchange. This segment goes between interchange nodes that are part of the same physical interchange.

Interface - **(1)** A shared boundary across which information is passed. (2) A hardware or software component that connects two or more other components for the purpose of passing information from one to the other. (3) To connect two or more components for the purpose of passing information from one to the other. (4) To serve as a connecting or connected component as in (2). (See IEEE Std 610.12-1990.)

Interface Control Specification Document (ICS) - A document prepared on all critical interfaces to specify physical connectivity protocols, message content, message structure, timing and control methodology.

Interface Requirement - A requirement that specifies an external item with which a system or system component must interact, or that sets forth constraints on formats, timing, or other factors caused by such an interaction. (See IEEE Std 610.12-1990.)

Interface Specification - A document that specifies the interface characteristics of an existing or planned system or component. (See IEEE Std 610.12-1990.)

Interface Testing - Testing conducted to evaluate whether systems or components pass data and control correctly to one another. (See IEEE Std 610.12-1990.)

Intermodal Surface Transportation Efficiency Act (ISTEA) - Public Law 102-240, Dec. 18, 1991. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 provides the primary federal funding ($15 1B) for all surface transportation programs in the U.S. for the six (6) year period 1992-1997. This legislation includes the Intelligent Vehicle-Highway Systems Act of 1991 (Title VI, Part B.)

Internal Interface - The software and hardware required to provide communications between systems internal to *ADVANCE* (i.e., between any combination of MNA, TIC, TRF and COM.)

Itinerary - The ordered list of one or more destinations which make up a trip.

Kiosk - Computer terminal display located in public area such as shopping center airport, office complex, etc., giving real-time traffic information for the purpose of trip/route planning. May also include information on services, facilities, etc.

Landmark - A landmark is a prominent object, visible from the road, at fixed location defined in the data base. By incorporating the names of landmarks, route guidance instructions are made less ambiguous.

Layer - A characteristic of a representation of the road network (which has no everyday informal analog) which simultaneously contains all information present at the given level and all levels above it. Layer n contains all segments and super-segments at level n and all levels above n. Hence, the primary difference from "level" is that it includes the simple segments creating the super-segment, as well as the super-segment. (Also see "Level.")

Leg - Leg, as in "leg of a multiple destination trip," is a portion of the trip corresponding to a single destination and its associated set of route criteria.

Level - The lower level representations have the most detail which the higher levels have progressively less detail. A level n network is constructed from segments of rank n and above. The segments on the higher level have been constructed by chaining together shorter segments of identical rank. These chained together segments are defined to be super-segments. The primary difference from "layer" is that the higher levels do not contain the simple segments creating the super-segment. (Also see "Layer" and "Rank" definitions.)

Level of Documentation - A description of required documentation indicating its scope, content, format and quality. Selection of the level may be based on project cost, intended usage, extent of effort, or other factors.

Link - See “Traffic Link.”

Locale - A named polygon which defines a geographical area.

Local Road - See “Functional Classification.”

Location - Defines a point on the road network. It is specified as a particular road segment a relative distance along the segment, and the right or left side of the segment.

LORAN-C - Land-based radio navigation system operated by the U.S. Coast Guard as a public service. This hyperbolic system uses signals broadcast from land-based radio towers.

Major Road - A major road is an expressway, highway, or arterial road designed for heavy thoroughfare. (Also see “Functional Classification.“)

Man Machine Interface (MMI) - The interface between the system hardware and the person who is using the system. This general term includes touch (for example, buttons, levers, or touch screens), vision (such as lights or various displays), and auditory effects (such as chimes, beeps, voice synthesis, and voice or speech recognition.)

Manual Incident Detection - The ability of the TIC operator to utilize data from other sources (e.g., traffic reports) to identify incidents on the network absent an automated detection process.

Map Matching - A technique to enhance and correct in-vehicle dead-reckoning. Computer software follows the progress of the vehicle through an on-board digital map and matches the dead-reckoned estimate of the current position to the closest point on the map in order to correct for accumulated sensor errors.

Measure of Effectiveness (MOE) - Used to evaluate results of operational field tests.

Member - Entities on the *ADVANCE* Steering Committee who were not one of the four (4) founding Parties. Generally, members have the same rights and privileges as the founding Parties.

Memory Card - A plug-in computer memory card containing prerecorded information. May function as mass storage for on-board navigation systems.

Message Framing - A method of processing data in which control bits are inserted to identify channels.

Message Sequence Numbers - Sequential numbers assigned pieces of a data message for reassembly.

Mobile Navigation Assistant (MNA) - An in-vehicle navigation system designed and built by Motorola that determines vehicle position, performs route planning based on current traffic information, and provides dynamic route guidance information to the driver.

Modem - A device that converts serial digital data from a transmitting terminal to a signal suitable for transmission over a telephone line to a receiving terminal.

Motorola - One of the founding Parties. Motorola is providing the in-vehicle systems as well as the RF communications systems.

Motorola Intermediate File (MIF) - The Motorola file that contains the hierarchal data base used to generate the map file for the MNAs. The MIF is created from the SIF (see definition below.) This is an off-line data base created at a Motorola facility.

National Highway Traffic Safety Administration (NHTSA) - A branch of the U.S. Department of Transportation that focuses on safety and standards.

Navigable Data base - A digital street map data base containing sufficient detail and scope to support driver and vehicle guidance applications (e.g., the generation by computer of a high quality driving route between two stated addresses.)

Navigation - The determination of the vehicle's position and direction of travel, utilizing information provided by GPS, or another internal position device and computerized maps.

Navigation Technologies, Corporation (NavTech) - NavTech is providing the map data base used in the *ADVANCE* project.

Network Flow Model (NFM) - The model developed by the TRF group based upon the contents of the *ADVANCE* Network Representation. The network flow model analyses the ANR to produce an output file containing link travel times and link flows by time period and day type.

Node - (1) In a diagram, a point, circle, or other geometric figure used to represent a state, event or other item of interest. (See IEEE Std 610.12-1990.) (2) A node is the intersection and/or interchange where two or more roadways meet or where a roadway begins or ends. For example, the intersection of Milwaukee Avenue and Lake-Cook Road is a node.

> *Node - Interchange.*
> A node specified to represent the physical nature of an interchange (e.g., layout of ramps) for route guidance purposes and to define a freeway or expressway segment and link.
>
> *Node - Intersection.*
> A node which represents the intersection of roadways that are not grade separated.

Non-Exception Probe Report Filter - Process in which some fraction of probe reports at a given level (based on some other qualifier) will be discarded.

Null Modem Cable - A device which interfaces between a local peripheral that normally requires a modem and the computer near it that expects to drive a modem and interface to that device; an imitation modem in both directions.

Object Oriented Analysis (OOA) - Attempts to define object classes associated with the objects and the relationship between different objects and classes in the systems problems domain. OOA attempts to understand the problem domain and what the systems responsibilities are for the problem domain.

Origin - The point on the roadway network from which route plans are made to the destination. With multiple destinations a trip plan may include up to four points of origin.

Outbound (RF communications message) - A communications message transmitted by the TIC to the probe vehicles.

Packet - A group of bits including information bits and overhead bits transmitted as a complete package on a packet-switched network.

Parity - A check bit defined to check if the correct number of bits are set for that character. *Examples*- odd, even, disabled (or no.)

Participants - Any firm, agency or individual, contributing to the *ADVANCE* project.

Parties - The original signees to the Agreement creating *ADVANCE.* Consists of Motorola, the FHWA, IDOT, and the IUTRC.

Performance - The ability of a system or subsystem to perform its functions.

Performance Evaluation - The technical assessment of a system, subsystem or component to determine how effectively objectives have been achieved.

Performance Requirements - A requirement that imposes conditions on a functional requirement. (See IEEE Std 610.12-1990.)

Performance Specification - A document that specifies the performance characteristics that a system or component must possess. (See IEEE Std 610.12- 1990.)

Position - The latitude, longitude, and altitude of a point on the surface of the earth.

Probe Vehicle - A vehicle (auto, bus, truck, etc...) equipped with the *ADVANCE* Mobile Navigation Assistant. The probe vehicle automatically reports travel times to the *ADVANCE* Traffic Information Center as it traverses the test area.

Quality Assurance (QA) - (1) A planned and systematic pattern of all actions necessary to provide adequate confidence that an item or product conforms to established technical requirements. (2) A set of activities designed to evaluate the process by which products are developed or manufactured. (See IEEE Std 610.12-1990.)

Quality Control (QC) - The procedures used for Quality Assurance.

Radio Data Link Access Procedure (RD-LAP) - A Motorola acronym for narrow band data communications protocol.

Rank - An attribute of the segment identifying its place in the road network hierarchy. The lowest ranking segments are residential, the highest ranking segments are interstate highways. Rank is an attribute of a roadway which indicates its functional classification. There are four (five for national implementation) road ranks defined. For the *ADVANCE* project, rank 4 would contain the major intercity routes. (Also see functional classification.)

Road ranks are defined (based on AASHTO classifications) and have the following general characteristics:

rank 0. (Corresponds to "Local" Functional Classification,) Local roads which provide land access to individual sites. These are low capacity/volume, low speed, local roadways (e.g., residential streets.)

rank 1. (Corresponds to "Collector" Functional Classification.) Collector roads which provide through movement and land access to local areas. These are moderate capacity/volume, low speed, through roadways.

rank 2. (Corresponds to "Arterial" Functional Classification.) Arterial roads which provide through movements between CBDs and some land access to secondary generators. These are high capacity/volume, moderate speed, extended roadways.

rank 3. (Corresponds to "Freeway" Functional Classification.) Freeways which provide through movement exclusively between CBDs and major generators. These are high capacity/volume, high speed, wide area roadways.

rank 4. (Corresponds to "Freeway" Functional Classification.) High capacity/volume, high speed, major routes between large cities extending outside the test area. (For national implementation of *ADVANCE* and other ITS projects.)

To provide useful map displays, a roadway should not be broken into multiple ranks, i.e., the entire roadway should be assigned to a rank based on its predominant capacity/volume and speed characteristics.

Recent Destinations - A list of the last seven destinations the vehicle has traveled under route guidance. This list is associated with the vehicle, not a particular registered driver.

Registered Driver - A driver who has input personalized information including name, into the MNA data base.

Registered Driver Data - A registered driver is a named collection of data associated with a user of the device. The data includes preprogrammed trips. The name of the registered driver is specified by the user when the data is created. A user of the device can instate a particular set of data when using the device by referring to it by name.

Requirement - (1) A condition or capability needed by a user to solve a problem or achieve an objective. (2) A condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed documents. (3) A documented representation of a condition or capability as in (1) or (2). (See IEEE Std 610.12-1990.)

Requirements Specification - A document that specifies the requirements for a system or component. Typically included are functional requirements, performance requirements, design requirements and development standards. (See IEEE Std 610.12-1990.)

Road Network - A road network is a collection of interconnected roadways. Typically, a road network covers a limited geographical area such as the Chicago Metropolitan area, but, it may cover a larger area.

Road Segment - A segment is the section of roadway between two adjacent nodes in a given road network layer. A segment at a higher network layer can be made of more than one segment at a lower layer. A road segment may contain zero or more shape points.

Roadway - A roadway is a continuous length of road having the same name. An example of a roadway is Dundee Road or Lake-Cook Road north of Chicago. It should be noted that two or more roadways may share the same section of road. For example, Northwest Highway is a roadway contained within the roadway named "US 14." Some roadways may not have any specified beginning or ending points due to their unusual topological nature.

Route Guidance - Route guidance is the process of the MNA of directing the driver along the established route. Route guidance instructions consist of a combination of display graphics, voice output, audible tones, and/or display text.

Route Guidance Mode - One of two preference choices for "Vehicle Use." Route Guidance Mode allows the user to determine distance to the next maneuver and is provided timing cues for executing the maneuver.

Route Plan - Defines roadway segments to be used in executing a route.

Route Planning - The process of selecting a travel route for a particular route. Route planning is performed by the MNA device. It takes into account user-specified conditions (e.g., detours and route criteria), and real-time traffic information.

Segment - A continuous point of a road which connects two intersections/nodes.

Segment ID - A unique ID that identifies each roadway segment. The ID consists of twenty three (23) bits as assigned by NavTech.

Selective Availability - A technique of deliberately introducing inaccuracy into GPS broadcasts for civilian applications.

Server - (1) A computer providing a service, such as shared access to a file system, a printer or an electronic mail system to LAN users. Usually a combination of hardware and software. There are variations on the same theme. They are called file servers and print servers. (2) The component in a computer system which will validate the client request for correct parameters and access privileges and then execute the requested task. It may return a message to the client. (Also see "Client" and "Client-Server.")

Shape Points - A node in the Road Segment used to define the curvature or alignment of the roadway.

Simple Link - A simple link is a link formed by a pair of adjacent simple segments. A layer 0 traffic link is a simple link. This is the lowest unit of road length for which a traversal time (measure of impedance) is associated. This concept is used by probe vehicle reporting and route planning.

Simple Segment - A simple segment is a road segment that does not have an intervening node(s) between the defining nodes of the segment at a lower network layer. All segments within layer 0 are simple segments. A simple segment can also exist at a higher layer. In order to determine if a segment is a simple segment, perform an analysis at layer 0 (Is this segment a simple segment at layer 0? If the answer is no, then it is not a simple segment.) Simple segments are used by vehicle positioning to perform map matching. Vehicle positioning always operates at layer 0 of a road network.

Smart Card - An electronic information carrier system that uses plastic cards about the size of a credit card with an imbedded integrated circuit that stores and processes information.

Specification - A document that describes in a complete, precise, verifiable manner, the requirements, design, behavior or other characteristics of a system or system component, and, often, the procedures for determining whether these provisions have been satisfied. (See IEEE Std 610.12-1990.)

Standard Interchange File (SIF) - The NavTech data base file supplied to Motorola to develop the MlF. This file contains geometry (e.g., the latitude and longitude for each roadway intersection) and attribute (e.g., classification, restrictions, etc.) information for each roadway.

Static Profile - Static information of the roadway link including day type, link ID and average travel times for a specific time period.

Static Route Planning - The process in the Mobile Navigation Assistant (as well as in the TIC for testing purposes) which uses data that represents travel time (or travel distance) to determine a recommended travel route. The algorithm is the same as that used in dynamic route planning.

Steering Committee (SC) - Consisting of one voting representative from each of the Parties and Members that provides overall direction to *ADVANCE.*

Stolen Vehicle Recovery System (SVRS) - Application of AVI/AVLM type technology with non route specific radio navigation tracking systems to allow locating and tracking stolen vehicles.

Stop Bits - The number of bits following a character in a transmission to define the end of a character.

Subsystem - A secondary or subordinate system within a larger system. (See IEEE Std 610.12-1990.)

Super Link - A super link is a link formed by a pair of adjacent super-segments.

Super-Segment - (1) A super-segment is a segment within layer 1, 2, or 3, containing one or more simple segments. A super-segment may also be a simple segment. Super-segments are used to control the amount of detail for purposes of map display, route planning, route guidance and probe vehicle reporting. (2) A generalization of the segment to the higher levels of the network. It is defined to be constructed by chaining together shorter segments of roadways of identical rank.

System - A collection of components organized to accomplish a specific set of functions. (See IEEE Std 610.12-1990.)

Technical Advisory Committee (TAC) - Formed under the auspices of the Steering Committee to provide detailed technical direction to the project.

Test Phase - The period of time during which the components of a hardware or software product are evaluated and integrated, and the product is evaluated to determine whether or not requirements have been satisfied.

Topologically Integrated Geographic Encoding & Referencing (TIGER) files - Computer-based map files created for the Census Bureau in support of the 1990 census. They contain DIME file data augmented with information for new suburbs and small cities (as of 1987) that were not included in the DIME files.

Traffic Information Center (TIC) - Consisting of the hardware, software, a centralized facility and operations personnel. It communicates to and from probes and external systems.

Traffic Link - A traffic link (or link, for short) is a pair of adjacent segments and its associated data within a given network layer. It should be noted that links are directional. Therefore, for adjacent bi-directional segments, there are two links defined, one in each direction. Physically, a traffic link consists of the portion of road from the detected beginning of a segment to the detected beginning of one of its successor segments.

Traffic Related Functions (TRF) - Subsystem consisting of data fusion, vehicle dynamics, incident detection and travel time prediction algorithms.

Traffic Systems Center (TSC) - Operated by IDOT to monitor and control the flow of traffic on expressways within the Chicago area.

Traffic System Center (TSC) Connection - The connection to the IDOT TSC which allows for electronic transfer of information from the TSC to the TIC for use in route planning, etc.

Travel Technology (TravTek) - A public/private partnership involving the City of Orlando, the Florida DOT, FHWA, General Motors, and the American Automobile Association. An operational test which provided motorists with traffic congestion information, motorist services (yellow pages) information, tourist information, and route guidance information

Travel Time Prediction (TTP) - An algorithm used in the prediction at the TIC of future short term travel times on links to develop future adjustments to the static profiles.

User - The person using the specific system referred to.

User Instructions - Documentation conveying to the end user of the system, instructions for using the system to obtain desired results.

User Maintenance Manuals - Maintenance manuals for the Mobile Navigation Assistant, the Traffic Information Center, and the Communications Subsystems as well as for interfaces for external systems connected to *ADVANCE.*

User Operations Manuals - Operating manuals for TIC Console Operators and TIC Data base Users.

User Training Manual - Training manual for operators of the probe vehicles. To be completed before beginning the deployment of the probe vehicles in 1995.

Validation - The process of evaluating a system or component during or at the end of the development process to determine whether it satisfies specified requirements. (See IEEE Std 610.12-1990.)

Vehicle Navigation and Information Systems (VNIS) - "Smart Cars" applications for vehicles and route guidance, vehicle location and traffic information displays on board cars and trucks. Utilizes map data bases and ETTM technology.

Verification - (1) The process of evaluating a system or component to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase. (2) Formal proof of program correctness. (See IEEE Std 610.12-1990.)

Verification & Validation (V & V) - The process of determining whether the requirements for a system or component are complete and correct, the products of each development phase fulfill the requirements or conditions imposed by the previous phase, and the final system or component complies with specified requirements. (See IEEE Std 610.12-1990.)

Verification & Validation Plan (V & V Plan) - *ADVANCE* document # 8300.

Verification & Validation Team (V & V Team) - The personnel assembled to develop and implement a Verification and Validation Plan.

Walk Through - A static analysis technique in which a designer or programmer leads members of the development team and other interested parties through a segment of documentation or code, and the participants ask questions and make comments about possible errors, violation of development standards, and other problems. (See IEEE Std 610.12-1990.)

Week - Seven (7) days, Monday to Sunday.

Work Day - Monday, Tuesday, Wednesday, Thursday, Friday excluding legal holidays acknowledged by the State of Illinois.

THE ADVANCE PARTICIPANTS

Founding Parties and Members

American Automobile Association
Federal Highway Administration
Illinois Department of Transportation
Illinois Universities Transportation Research Consortium
Motorola

Associates

Ford Motor Company
General Motors Corporation
Sun Microsystems, Inc.
Surface Systems, Inc.

Sponsors

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Navigation Technologies
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Toyota Technical Center, Inc.

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