Evaluating Effectiveness of Real-Time Advanced Traveler Information Systems Using a Small Test Vehicle Fleet

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ADVANCE was an in-vehicle advanced traveler information system (ATIS) providing route guidance in real time that operated in the northwestern portion and northwest suburbs of Chicago, Illinois. It used probe vehicles to generate dynamically travel time information about expressways, arterials, and local streets. Tests to evaluate the subsystems of ADVANCE, executed with limited availability of test vehicles and stringent scheduling, are described; they provided useful insights into both the performance of the ADVANCE system as a whole and the desirable and effective characteristics of ATIS deployments generally. Tests found that the user features of an in-route guidance system must be able to accommodate a broad range of technological sophistication and network knowledge among the population likely to become regular users of such a system. For users who know the local network configuration, only a system giving reliable real-time data about nonrecurrent congestion is likely to find a market base beyond specialized applications. In general, the quality and usefulness of systemwide real-time route guidance provided by other means are enhanced significantly by even a small deployment of probes: probe data greatly improve static (archival average) link travel time estimates by time of day, although the guidance algorithms that use these data should also include arterial traffic signal timings. Moreover, probe- and detector-based incident detection on arterial networks shows considerable promise for improved performance and reliability.

ADVANCE (Advanced Driver and Vehicle Advisory Navigation Concept) was an in-vehicle advanced traveler information system (ATIS) that operated in the northwest suburbs of Chicago, Illinois. It was designed to provide origin-destination shortest-time route guidance to a vehicle based on an on-board static (fixed) data base of average network link travel times by time of day, combined as available and appropriate with dynamic (real-time) information on traffic conditions provided by radio frequency (RF) communications to and from a traffic information center (TIC). Conceived in 1990 as a major project that would have installed 3,000 to 5,000 route guidance units in privately owned vehicles throughout the test area, ADVANCE was restructured in 1995 as a targeted deployment, in which approximately 80 vehicles were to be equipped with the guidance units—mobile navigation assistants (MNAs)—to be in full communication with the TIC while driving the ADVANCE test area road system. Figure 1 is a schematic of the dynamic information flow in ADVANCE.

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Because it originally was to have been evaluated formally as a fully deployed field operational test (FOT), ADVANCE required a modified evaluation scheme so that it could be realized as a targeted deployment. Such a plan was constructed by Booz Allen & Hamilton, FOT support contractor to the FHWA Joint Program Office. The *ADVANCE Evaluation Management Plan* (*1*) identified the roles and responsibilities of the test program participants, delineated the data management requirements, provided a resource management plan for the test vehicle fleet, and included detailed schedules for the completion of each evaluation task. This document, in concert with the *ADVANCE Evaluation Program Plan* (*2*), served as the foundation on which test plans were developed, through extensive cooperation between staff and the evaluators, to direct data collection and management, analysis, and task management efforts for each of the individual tests.

Three of the four ADVANCE subsystems were formally evaluated, as well as focused evaluations of the performance of the system in its entirety. The evaluated subsystems were traffic-related functions (TRF), MNA (examined in the context of its user friendliness/acceptance and its performance in route guidance), and TIC. The interaction of these subsystems in concert with the RF communications subsystem (COM) was performance-tested by the dynamic route guidance and incident detection field evaluations.

TEST BASES AND CONDUCT

As described in the following, testing was conducted in the field and at the TIC in support of performance evaluation for each of three major ADVANCE subsystem features.

TRF Subsystem

The TRF algorithms used by ADVANCE were resident in the central computing facilities of the TIC. Their primary purpose was to screen, validate, and then process incoming real-time data from loop detectors (traffic volume and occupancy), MNA reports (link travel times of probe-equipped vehicles called probes), and any anecdotal information (such as emergency vehicle dispatch reports) to generate near-term estimates and predictions of travel time along any link. These reports and their resulting link travel time estimates were compared with values in the stored data base of historical average travel time for that day of the week (measured for normal weekday, normal weekend, and Friday/holiday) and time of day (five time periods). If certain criteria were met, a travel time update would be included in a message bundle for RF transmission to MNAs.

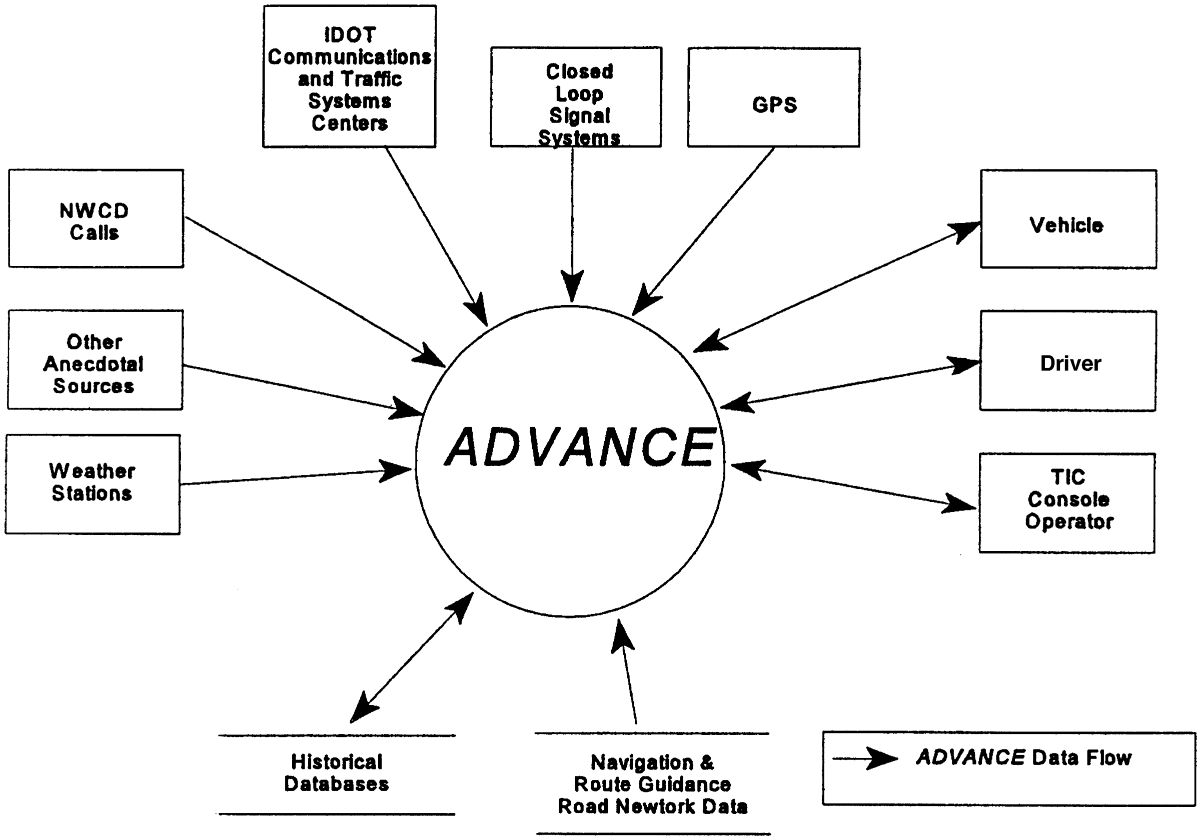

FIGURE 1 Dynamic information flow in *ADVANCE*.

The base travel time values against which real-time data were compared had been generated by either a network equilibrium flow model or a static profile update incorporating real traversal time measurements. The navigation network used by ADVANCE for real-time travel updates contained 7,253 directional segments with 1,580 intersections, of which 699 were signalized. To code this network for appropriate representation as a data base, 274 boundary segments were defined around the test area, while every approach segment to an (eligible) turning movement was expanded to add a turning movement segment (this latter modification alone increased the number of coded links by a factor of 2.5). Turning movements and arterial signals were abstracted as delay functions.

In every 5-min interval, TRF screened incoming data, then executed the following tasks:

1. Determined the presence of a lane-blocking or flow-retarding condition on any link by comparing probe traversal time and loop detector volume and occupancy reports with the static profile, or by directly incorporating an anecdotal incident report; if time difference criteria were met, an incident report/flag for that link was generated.
2. Estimated current travel time on the basis of fusion of detector (where available) and probe data, or individually if either source were missing or had failed screening criteria. When both sets of data were available and screened as acceptable, the travel time estimator fused them in an equation incorporating adjustment factors weighted according to (*a*) the standard deviations of the average travel time estimates from each source, and (*b*) how detector travel time should be weighted in the combined estimate.
3. Computed travel times on the link for the next four 5-min intervals (i.e., up to 20 min into the future). The TIC used probe and fusion data in this computation except where an incident had been confirmed, in which case the expected incident duration was applied. It standardized the link data by mean and standard deviation of the combined probe and detector values, and predicted travel times in a function that gradually "decayed" back to the static average time after the last 5-min interval. Each outgoing message contained all four 5-min computed values.

Additional information on the development and validation of the TRF algorithms is available in the technical reports archive located on the ADVANCE project's Internet home page at URL **http://ais.its-program.anl.gov/**. Selected key reports have been included in the reference list of this paper (*3–8*).

The purpose of the TRF subsystem field tests was to evaluate the performance of the components of the subsystem and the relative usefulness of probe-equipped vehicles, in-pavement loop detectors, and anecdotal incident reports in providing real-time traffic data. Specific questions to be answered were

- How well did the static profile, data screening, detector travel time conversion, data fusion, incident detection, and travel time prediction components of the TRF perform?
- How accurate were the travel time estimates generated by the network flow model, used before system deployment to simulate traffic activity in the ADVANCE area?
- What is the comparative value of fixed detectors and probe vehicles as sources of information for the incident detection and travel time prediction algorithms?

- What frequency of probe reports is needed to obtain reliable estimates of current link travel times and identification of nonrecurrent congestion?
- What is the accuracy of the probe travel time reports?

The procedures developed for the seven interrelated TRF field tests, managed by the University of Illinois at Chicago's 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 traversal times and other indicators of network performance for each link (e.g., distances traveled at speeds less than 22.5 mph and time spent at less than 5 mph) were recorded at the TIC, along with arterial loop detector data. Figure 2 shows the primary route used.

Analysis of performance indicators assessed (*a*) response, accuracy, and usefulness of the key TRF components, including fusion of data received from probes and detectors into a travel time prediction algorithm; (*b*) construction of both the default static forecasts and the on-line dynamic forecasts; (*c*) estimation of the number and frequency of probe traversals required for reliable travel time updates; and (*d*) relationship among vehicles' travel times on a link as a function of turning movement and direction.

One of the principal purposes of the TRF and TIC functions was to generate, in real time, link travel time updates that could be broadcast to MNAs and enable them to determine a near-optimal (least-time) point-to-point route at a given time interval. A test was constructed to determine whether, and to what extent, dynamic route guidance (DRG), as implemented in the ADVANCE system, could significantly improve travel times for drivers. The test had two central facets: yoked-driver (YD) timing and incident detection (ID) timeliness.

In the DRG/YD tests, a group of three equipped vehicles operated by paid drivers were driven, starting at approximately identical times, between a preselected origin and destination. Two members of each group 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 to ensure the success of the test even if equipment in one vehicle malfunctioned. Eighteen 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. An example of one of these origin-destination networks and possible routings is shown in Figure 3. The objective of the test 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 that saved time or had a potential time-saving benefit relative to the static route. These tests, managed by faculty of the Northwestern University Transportation Center (NUTC), were conducted weekdays and early evenings through September 1995 using drivers hired by Northwestern University.

In the 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 probes 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 (*a*) nonrecurring incidents and construction, and (*b*) incident delays by means of loop detector data and data fusion was evaluated with data collected from these traversals. Tests were conducted by NUTC during weekday periods of recurrent, nonrecurrent, and incident-related congestion (both naturally occurring incidents and staged incidents were used) during summer and autumn 1995.

MNA Subsystem

Look, Feel, and Capabilities

The MNA hardware configuration installed in ADVANCE-equipped vehicles included a display unit, located next to the driver, with a (PCMCIA) memory card; a speaker for audio messages; a gyrocompass and transmission pickup for dead-reckoning navigation, mounted inside the vehicle frame; antennas, attached to the rear exterior of the vehicle, for transmitting and receiving RF messages and for receiving global positioning system (GPS) signals; and a navigation computer, sensor controller, RF modem, GPS receiver, and CD-ROM drive, all mounted in the trunk (or rear of a minivan's passenger compartment).

The navigation computer was activated when the vehicle was started, becoming functional after about a 1-min warm-up, and shut down after safely closing out all its active functions when the ignition

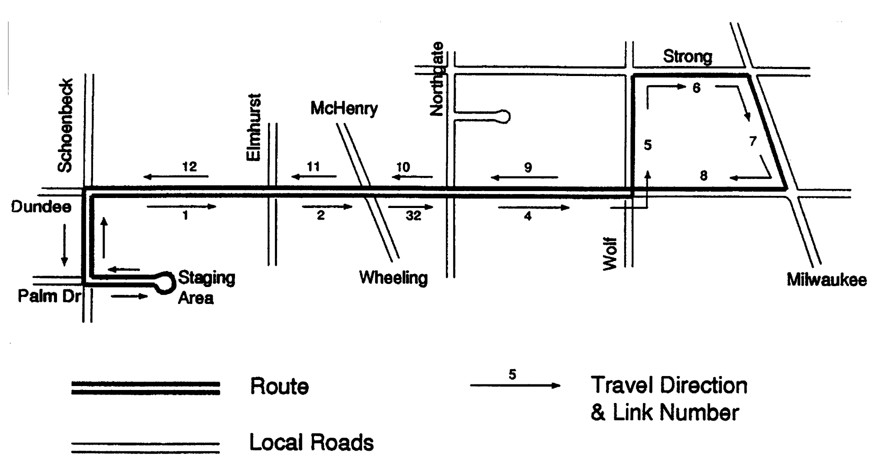

FIGURE 2 Primary route used in TRF field tests.

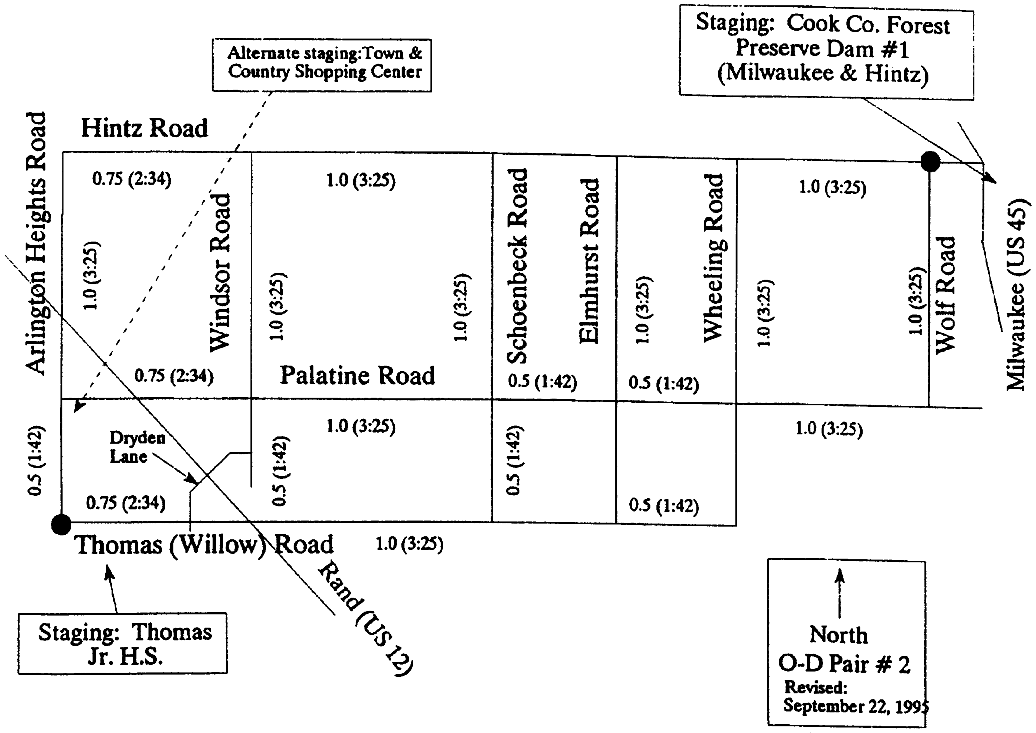

FIGURE 3 Example origin-destination pair for YD test.

was turned off. It was designed to function in ambient temperatures ranging from –40°C to +85°C and (–40°F to +185°F) and was capable of operating effectively in a rough-service environment with respect to impact shock, vibration, and voltage spikes.

The display head to the driver's right contained a 14.5-cm (5.7-in.) diagonal screen featuring an infrared-based touch panel with backlit color liquid crystal display (LCD). A memory card slot housed a 2 MB PCMCIA card (formatted to 1.44 MB) that stored link traversal data and other messages transmitted to and from the TIC. This memory card supplemented retrieval and storage of data to be used in the evaluation. Buttons to the right of the screen or touch prompts on the screen itself could be pressed to bring up one of the following principal displays:

1. A selection menu for route planning, network/location map, or user interface adjustment.
2. *Route planning* mode: an option to select destination by address or intersection; up to seven addresses can be stored for future use and accessed from a screen linked to Display 3.
3. Following Display 2, an alphanumeric touch keypad to enter destination street names, address numbers, and/or towns in the ADVANCE data base (a choice of streets or towns is offered by pressing ENTER on the touch pad).
4. Following Display 3 and the best route computation by the system (which uses the static network data on the CD-ROM and/or real-time information transmitted from the TIC), the LCD displays a straight-ahead, left-, or right-turn arrow indicator of the distance to the next required turn (onto the street listed at the top), supplemented by an auditory cue as the turn approaches. The street on which the vehicle is *currently* traveling is printed at the bottom of the display, which refreshes with a new direction and street name as each turn maneuver is accomplished, until the destination is reached.
5. *Map* mode: a "zoomable" north-up portion of the map network approximately centered on the vehicle's current location; this location is indicated by (*a*) the name of the street currently occupied (at the bottom) and the next street to be intersected (at the top); (*b*) a solid circular icon based on the GPS locator, surrounded by an orange ring if the vehicle position is receiving GPS range correction from the TIC (if the color of the solid circle changed from green to yellow, the GPS signal was being received from only three satellites; upon further loss of the signal, no circle whatsoever is shown); and (*c*) a red triangle indicating the vehicle's position according to the MNA's map-matching and dead-reckoning computer function.
6. *ADJ* mode (accessed by a button on the display head): a prompt to change display brightness or volume of the auditory cue.

A few additional screens in the MORE mode, also accessed by button, enable users to identify or respecify the trip starting point, enter their user identification and password, and modify other system control parameters. These screens were rarely accessed by drivers who operated project cars during the targeted deployment.

In ADVANCE, the planned route was not highlighted in map mode. The user could review an entire route in navigation mode by repeatedly pressing the "next maneuver" panel on the turn-arrow display until the destination screen appeared. It was also possible to display the selected route length in miles (from origin to destination only, not from some intermediate point). If a driver deviated from a planned route in navigation mode, an off-route indicator appeared, accompanied by a warning chime and a query as to whether a route to the destination should be replanned from the current location. Touching the YES display button would reactivate the route planner, and the turn-arrow display would reappear shortly with the first maneuver in the new route sequence.

As applicable, real-time information passed from the TIC would indicate that a route different from that originally plotted could save at least 2 min. At this point, the display would chime and a window would pop up to provide the user the predicted total time savings and ask whether the new route should be taken; if YES was touched, the turn-arrow display would return with the first maneuver of the new route from the vehicle's current location.

Volunteer Driver Experience

It had always been intended that drivers resident in the study area be given the opportunity to experience the look, feel, and capabilities of the ADVANCE MNA for an extended period in their own cars and trucks. The targeted deployment reduced the opportunity for such an immersion experience to 2 weeks in a project vehicle. Nevertheless, evaluators believed that such a brief volunteer driver acquaintance with a prototype system could generate much useful information for the *future* development of in-vehicle navigation products and services. Thus, a focused test using study area residents was devised to provide drivers familiar with the test area 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 contribute useful perspectives on the characteristics and performance of the ADVANCE system and could help guide the design and development of future ATIS services. The tests involved families living in the test area that had volunteered to drive ADVANCE-equipped, project-supplied vehicles for a 2-week period. These volunteer drivers completed both baseline and post-test surveys and maintained logs that noted malfunctions, problems, reroutes, and the drivers' responses. Subsequently, 30 percent of these drivers participated in focus groups that examined their experiences and reactions. This test and the follow-up focus groups were managed by Northwestern University.

TIC Subsystem

The TIC, located at the ADVANCE project office, provided all centralized computing resources for the system, including processing, distribution, and archiving of system descriptive (static) and real-time-generated (dynamic) data. The central computer was a Sun SPARC 70 multiple-processor server having 128MB dynamic random access memory available, along with a 13.6GB disk drive, a 5.0GB capacity off-line tape drive (for storage and archiving), and a CD-ROM drive. The rack modem for receipt of external data supported 16 slots (for the two 16-port synchronous interface cards) at 14,400-baud rates. The main operator consoles were Sun SPARC X-Windows terminals linked to the server by 10 BaseT Ethernet cabling.

All TIC software modules (including TRF processes, described later) interacted with the TIC data base and each other, using interprocess communication protocols without interrupts. Static data included the digital map data base of the road network, including link-by-link average travel times by time of day based on either the results of a network flow model or an updated (static profile) value derived from actual measurement. Dynamic data included expressway and arterial loop detector reports, vehicle probe travel time reports, incident reports from a regional 911 system, and any relevant weather data. Inbound message processes validated and managed reception and storage of reports from the Traffic Systems Center (expressways), Illinois Route 68 loop detectors, and probe vehicles (MNAs), whereas the outbound processes involved a message scheduler that grouped updated dynamic data into packets for RF transmission to MNA-equipped vehicles. During the targeted deployment, these updates were transmitted at 4-sec intervals, every fourth message being a differential GPS range correction. Outbound link update messages contained the 10-digit link identifier and travel time predictions for the current and ensuing 5-, 10-, and 15-min intervals. These messages (for any link) were transmitted as frequently as the volume of updates permitted.

At any given time the TIC was simultaneously (*a*) receiving inbound information by RF on an almost continuous basis; (*b*) sorting and directing this information to log files, display windows, and/or TRF processing algorithms; and (*c*) preparing and scheduling for RF transmission outbound messages to project vehicles (about 15 times per minute). Up to 10 windows could be displayed simultaneously on the TIC console for operator viewing, use, and monitoring of system functions.

The purpose of the TIC evaluation conducted under the targeted deployment was to analyze the TIC hardware and software as a combined system, documenting reliability; examining system staffing, operation requirements, and overall cost efficiency; and assessing system design alternatives from the perspective of system transferability (to other sites and applications), maintenance needs, and ease and effectiveness of use by operators. This evaluation began with a pilot test in September 1995, with the most intense activity occurring from October through early January 1996. Following a thorough review of system specifications, evaluators assembled data by means of the TIC real-time log, in which are recorded known times and dates when malfunctions occurred. When a malfunction was identified, this log provided information on cause and remedial actions taken. Other automated logs created by the system describing separate processes were also examined, as were logs of such nonautomated functions as the entry of police dispatch and anecdotal traffic incident reports. Time stamps on each of these logs indicated how long it took for the TIC to formulate and transmit dynamic traffic messages, with and without operator intervention. Tests were performed to ascertain the maximum amount of data that could be entered into the system before incoming data were lost because of system overload. These tests determined if the TIC was adequate for the amount of data that required processing during the targeted deployment. In addition, measurements were made of the duration of the backup cycle necessary to avoid compromising TIC functions.

Data were collected on the operational efficiency of the TIC in the absence of human intervention. This information was obtained by computing the amount of data entered *manually* as a percentage of *total* data used by the TIC (most data enter and are processed by the system automatically). TIC architecture capital and operating costs were assessed on the basis of all the available expenditure information provided by project partners and the ADVANCE project office.

The effects of policies, procedures, and staffing levels of efficient TIC operation were investigated by means of a structured questionnaire, observations, and informal discussion sessions with TIC operators and supervisors. The questionnaire was administered very late in 1995 to provide for maximum exposure of the operators to procedures in place at the TIC. In addition, a manual TIC-operator observation log was available at all times during the TIC architecture evaluation period to enable operators or the supervisor to note any issues relevant to operational practices. The evaluators briefed

TIC operators and their supervisor at the outset of the evaluation period on the purpose and scope of the operational practices evaluation, informed them of the purpose of the TIC-operator observation log and evaluator observations, and notified them that they would be interviewed near the end of the evaluation period.

A structured questionnaire, evaluator observation sessions, and related log sheets were used to assess various aspects of the usability and functionality of the TIC user interface. The usability evaluation considered such elements of the interface as workstation layout, screen format, task and menu structure, demands made on the operator by the system for data input and process monitoring, and degree of feedback provided by the system to the operator. The functionality evaluation involved an assessment of interface features to identify additional features that might be required or desirable, as well as any features already provided that were superfluous.

COM Subsystem

Because a proven product was employed, no formal testing of the fourth subsystem, the RF communications (COM) component, was conducted as part of the targeted deployment. The successful functioning of the other three components was always dependent on the efficient functioning of COM, so to the degree that these other subsystems performed according to specification and fulfilled their desired objectives during the targeted deployment, COM was also successful. Moreover, no weaknesses or malfunctions of any of the other subsystems during testing were ever attributed to a failure of COM as an independent operation (i.e., when its response performance, such as for providing differential GPS corrections, was unaffected by the response time delays for other MNA functions).

DATA CAPTURE AND ARCHIVING

Electronic Reports

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, Northwest Central Dispatch (NWCD) incident reports, TRF messages (travel time projections), and differential GPS (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, which was transmitted via a T3 telecommunications link to a data server/host at Argonne. The Argonne server automatically uncompressed the 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 Argonne server were made available by Internet FTP or http links to remote locations for downloading and analysis by evaluators.

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 2MB (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 2-sec intervals as referenced to a map grid developed by Motorola. These binary-coded files were converted to ASCII at the TIC, then both the original binary and new ASCII files were transmitted electronically to Argonne. The ASCII files were installed weekly on the data page as dated entries in a special subdirectory.

Familiar Driver Data Collection Instruments

Continuous monitoring of vehicle movements was neither necessary nor desirable during the 2-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 types of information-recording instruments as part of their agreement to participate in the program:

1. Baseline survey, filled out before 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 two) in the household;
2. Reroute logs, to be filled out during the 2-week period at any time that a driver decided not to use a route provided by ADVANCE or received an alternative routing option while following an MNA-preplanned route; and
3. Exit survey, recording each driver's overall end-of-test response to and reactions about the 2-week route guidance experience.

Obtaining the completed first instrument was 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 reroute log, whereas a few completed as many as 20. Obviously, there was no way to verify that all reroutes were recorded by each of the 74, or that no reroutes were actually presented to or undertaken by the remaining 6. Finally, 78 of the 80 households returned the exit survey.

All manually recorded instruments from the familiar driver tests—baseline surveys (130), reroute logs (74 sets, or about 400 individual logs), and exit surveys (110)—were coded and uploaded to the data page by Argonne for ease of tabulation by NUTC staff.

Data capture and archiving were generally successful from early June through August, despite the brutal heat on most test days; after overheating problems with the CD-ROM drives were mitigated, the only systematic log data losses occurred on those few days when the TIC went down for brief periods or was not started properly in the morning (resulting in the daily log storage process failing to execute and null files being generated for some logs). In most cases, after July, data lost in this manner could be reconstructed from memory card files. Archiving success was somewhat more uneven during the autumn months. At one point in late September, both a loss of log data and a malfunction of PCMCIA functions in one or more vehicles (plus a possible failure to download data from one vehicle's card for a particular week) resulted in irrecoverable loss of some electronic yoked vehicle test records during the incident delay simulation phase of the DRG evaluation. Thus, much of the incident simulation portion of the DRG tests ended up relying on manually collected driver logs for route timing information.

On January 8, 1997, the ADVANCE steering committee approved full disclosure of the contents of the data page, with appropriate annotations, to the research community at large, and this archive is now fully accessible at the project's Internet site.

RESULTS

Reports from 50,620 probe traversals were collected during the TRF field tests and examined. Of these, 88 had unacceptably high speed, 95 had unacceptably high congested distance (longer than the link itself), and 115 had an unacceptable match between congested distance (i.e., distance on the link traveled at speeds at or less than 10 m/sec, about 22.5 mph) and congested time (i.e., time on the link spent at speeds at or less than 2 m/sec, about 4.5 mph). Of those 115 reports, 11 were also in the set of unacceptable speed reports. Thus, 287 reports were found to be suspect, or about 0.6 percent of the total, and many of these were traceable to a single faulty MNA. Further, when 776 of these probe-reported values were compared with manually recorded values observed at the same time, 87.6 percent of values were within ±5 sec and 94 percent within ±10 sec, with substantial clustering within 2 sec or less. The overall conclusion is that MNA data proved a reliable indicator of traffic conditions in ADVANCE and thus could provide a valuable resource for traffic monitoring and analysis in future ATIS deployments.

After two or three updates based on probe traversal data, the static (average) profiles of travel times by time of day in the ADVANCE network became very accurate. Updated algorithms performed well against occasionally idiosyncratic probe reports, and data were screened appropriately, eliminating many reports from malfunctioning MNAs. Profiles based on probe data only were found to be more accurate than those based on both probe and detector data.

In most instances, three probe reports per 5-min interval were adequate to provide reasonable travel time estimates and predictions on the arterial system. Increasing this probe rate produced very little change in the output forecasts, a result consistent with an evaluation of probe frequencies, which found that the variance of arterial travel time estimates never approaches zero regardless of the number of probes, and that the quality of estimate essentially stops improving above relatively few traversals per 5-min interval. These factors argue strongly that very high levels of probe deployment are probably not necessary for an effective probe-based ATIS. However, all prediction algorithms would be enhanced by the inclusion of traffic signal timing data for roadways.

The user features of an in-route guidance system, such as those of the MNA units deployed for ADVANCE, must be able to accommodate a reasonably broad range of technological sophistication and network knowledge among the population likely to pay for and regularly use such a system and its associated services. Specifically, the capability should exist to "train" the system to learn the user's preferred routes, then provide timely and relevant information about available time savings on alternative routes (especially those that may be counterintuitive to a user familiar with the area road network). In general, users who regularly drive in a road network and know its normal traffic and congestion patterns tolerate recurrent time-of-day delays in the network on the links with which they are familiar and comfortable; thus, only a route guidance system capable of providing reliable real-time data about nonrecurrent congestion is likely to find a market base beyond specialized, limited applications. More detail on the results of this analysis is given in another paper in this Record.

For successful identification of instances of nonrecurrent congestion, results of testing the ADVANCE incident detection algorithms were mixed. Although the composite results of the evaluation called into question the ability to generally apply previously estimated freeway/expressway incident detection algorithms without completely recalibrating the parameters, they revealed substantial potential for further development of reliable arterial incident detection algorithms based on volume and occupancy data from fixed detectors or link traversal data from probe vehicles. A modified algorithm based on probe and detector data in the arterial system that used data from three probe traversals per 15 min detected nine of nine incidents without false alarms.

In the DRG/YD tests, it was established that route diversions and travel time savings are sometimes associated with the use of real-time data for route planning, but in an arterial network such as that of ADVANCE, in which DRG is subject to key functionality limitations, large time savings may not be a typical outcome. Where substantial time savings occurred during the test, the cause appeared to be the availability of less congested (but, paradoxically, *longer or orthagonal*) links proximate to highly congested routes. Such alternative routes, in the absence of DRG, are likely in most instances to appear illogical to drivers on the congested route and thus unlikely to be found and followed without a route planner using real-time information for the entire network.

Evaluation of the TIC confirmed that the TIC architecture as implemented provided an acceptable level of performance for the demands made on it by the targeted deployment with respect to both hardware and software as individual components and as a complete system. Moreover, it provided an acceptable cost efficiency for the scope of its mission, enabled successful system operation, ensured reasonable operator workload with its procedural practices, and provided an acceptable level of usability and functionality of user interface (although operator comments about unused features and suggestions for additions and enhancements indicated that many features of this interface might be improved). However, it was found that the architecture as implemented for the targeted deployment operational tests is not directly or immediately expandable to cover additional services within the current test area because of inherent system limitations deriving from reduced project scope. Nor is it directly transferable to other geographic areas because it was a unique technical solution that, as an entire system, has limited application and capability to meet local requirements in other areas. The prospects for transferability of its major system components are very good.

CONCLUSIONS

The decision to restructure ADVANCE as a targeted deployment meant that some of the project's original objectives were not fully met. A large-scale field test with 3,000 vehicles acting as probes was never realized. The scope of testing of DRG capabilities, the effect of the system on "familiar" drivers, and the ability to assess long-term operational and maintenance aspects of the system were far more limited than the original concept stipulated. Commercial trucking operations and fleets were not involved in the deployment, and experience gained in driver recruitment and training and vehicle installations of the MNA system represented less than 5 percent of original expectation. In emphasizing specific corridor and subarea concepts rather than areawide performance, due to deployment limitations, the project tests had a much-reduced ability to estimate the overall effectiveness of probes in conveying actual traffic conditions to a public information source. The project could not achieve statistical reliability, attributable to the large accident and incident data base that could be potentially assembled under full deployment, for a comprehensive evaluation of MNA use by and distractions of drivers. Also, the volume of data collected from the targeted deployment field tests, which would have been limited in any case, was further diminished by still-unaccounted-for losses in the transmission and archiving of electronically collected records; this problem impaired even some tests with relatively modest objectives.

Nevertheless, a subset of results of the ADVANCE evaluation would not change regardless of the scale of deployment.

- The user features of an in-route guidance system, such as those of the MNA units deployed for ADVANCE, must be able to accommodate a broad range of technological sophistication and network knowledge among the population likely to pay for and regularly use such a system and its associated services. Specifically, the capability should exist to "train" the system to learn the user's preferred routes, then provide timely and relevant information about available time savings on alternative routes (especially those that may be counterintuitive to a user familiar with the area road network).
- Users who regularly drive in a road network and know its normal traffic and congestion patterns tolerate recurrent time-of-day delays in the network on the links with which they are familiar and comfortable; thus, only a route guidance system capable of providing reliable real-time data about nonrecurrent congestion is likely to find a market base beyond very specialized, very limited applications.
- Although real-time guidance on arterial networks can be provided, at significant public expense, in the absence of equipped vehicle probes, its quality and usefulness would be much diminished relative to what even a small deployment of probes could achieve.
- Quantity and timeliness of data flowing into a properly functioning TIC (that is, a center capable of fast and reliable message processing and turnaround) argue strongly that such a center will not achieve full potential until integrated with a traffic management center able to intercede directly in modifying network flows.
- Route guidance algorithms that use probe data can be improved by including traffic signal timing data from the arterial system. The probe data itself significantly improve static (archival average) link travel time estimates by time of day.
- Probe- and detector-based incident detection on arterial networks show promise for improved performance and reliability.

From a practical standpoint, a number of lessons were learned about operating an FOT, whether full-scale or otherwise; these lessons are discussed in depth in a series of "Insights and Achievements" white papers (*9*). In larger-scale deployments, project practices would have to be adjusted to yield broader, perhaps more fundamental, discoveries about the limits, proper role, and driver acceptance of ATIS. However, because ADVANCE seminally investigated the properties and performance of important ATIS concepts (deployed in a limited yet focused manner), most of its findings have wide-ranging implications and other deployments cannot afford to ignore them.

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