Making Intelligent Vehicle/Highway Systems Really Work: A Status Report on the Congestion Avoidance and Reduction for Autos and Trucks Project

DAVID T. HARTGEN AND EDWARD L. BRUCE

Most Intelligent Vehicle/Highway Systems (IVHS) studies focus on the characteristics of selected technologies operating in narrow limited environments, consisting of a few selected corridors or markets in the largest cities. If successful, such applications would have a small overall effect on congestion. A different approach—placing full-service technologies into the hands of all drivers in medium-sized cities—holds much greater promise for real impact. One such proposal for the Charlotte, North Carolina, metropolitan area, a region of 1.6 million people, is described. Termed CARAT (Congestion Avoidance and Reduction for Autos and Trucks), the concept is an information provision (ATIS) element of a broad congestion and traffic management strategy being developed by the North Carolina Department of Transportation. CARAT envisions a large information network based on middle-tech devices, serving consumers, truckers, fixed sites, and emergency services. Telephone, radio, and other selected audio systems are used to transmit data directly to clients from a central office using straightforward geographic information system–based information storage technology. Only marketable and cost-effective services are offered, at low subsidy. CARAT would be partially supported by private-sector advertising and subscriptions. A careful market survey is being used to gauge the demand for services before implementation. A parallel effort to outfit the greater Charlotte freeway and expressway system with modern ATMS traffic operation technology is also in the development stage. The CARAT approach is not only feasible, but more cost-effective and more widely applicable than its high-tech IVHS cousins.

Intelligent vehicle highway systems (IVHS) are modern communications systems that give the driver real-time information on highway conditions (*1*). A variety of technologies are now available or emerging that permit the driver to receive data or warnings on traffic congestion, incidents, weather, and safety, as well as to transmit information on the vehicle's location to others. The devices can be as simple as radio or cellular telephone systems with electronic roadside sensors, or more complex with on-board electronic maps, in-street traffic detectors, satellite location systems, and on-board information systems. Other companies are experimenting with high-speed crash-avoidance technologies that would permit closer spacing on freeways and higher traffic volumes (*2*). Drivers use the information to avoid or reduce congestion or incidents, thereby saving time, fuel, operating costs, and accidents. These systems have been given much attention in the last 5 years, particularly in Europe and Japan, where they are seen as providing significant congestion relief, fuel savings, and safety improvements. In Europe, governments and businesses have combined under a broad project known as Prometheus, the goal of which is to reduce accidents and congestion by 40 percent (*3*). In Japan, a similar project would control traffic flows for a 300-mi^2 area of Tokyo (*4*). Each of these projects is very large, proposing \$700 million to \$800 million in expenditures.

D. T. Hartgen, Department of Geography and Earth Sciences, University of North Carolina, Charlotte, N.C. 28223. E. L. Bruce, Federal Highway Administration, Atlanta, Ga.

In the United States several demonstrations of these technologies have been initiated on a smaller scale. In Los Angeles, the Pathfinder project is using about 25 cars to test motorist information use in the congested Santa Monica corridor. In San Francisco, a tourist-oriented map system is being tested at airports and hotels. In Orlando, a demonstration of providing tourist information to drivers, TRAVTEK, is being tested. In New York, traffic flow coordination on the Long Island Expressway is being implemented (*4*). The federal government has initiated limited funding for IVHS research: \$150 million is being suggested for each of the fiscal years 1992 to 1996 (*5*). The U.S. General Accounting Office (*6*) has concluded that the technology can be useful but must be pursued aggressively.

However, the present studies focus primarily on large cities, with limited general application to the congestion problems of most U.S. cities. Systems concentrating on one large corridor in a metropolitan area are likely to have very limited local effect if not applicable beyond that corridor. One study by the authors suggests that overall IVHS adoption and use rates in major cities would have to be at least 50 percent before even slight (5 percent) changes in congestion could be noticed (*7*). More generally available technologies capable of more extensive use in a variety of settings are needed if IVHS is to ultimately be a cost-effective way of reducing traffic congestion. There is a need to develop and test systems that cover wider applications of congestion problems in many more places. Mid-sized cities such as Charlotte and its surrounding communities are more typical of the U.S. situation and provide an opportunity for tests and demonstrations that can be transported to other sites.

The fundamental problem that needs to be addressed in IVHS technology is not whether the technology will work (it has generally been established that the technology will work), but rather its cost and value to the average user. Supply and demand, balanced by costs and the characteristics of these technologies in a mix of marketplace services, will ultimately determine whether or not the demand for these technologies is sufficient to justify investments in their development and implementation. Unless IVHS supply and demand can be balanced at a reasonable price to consumers, services must be cut back or made more specialized or, alternatively, subsidized with the intent of gaining additional benefits to users and nonusers. Such assessments cannot be undertaken using small demonstrations of technology, but rather must be subjected to the hard spotlight of choices made by consumers in the course of everyday behavior.

The intent of this paper is to describe a recent effort to develop and implement a full-service IVHS program for the Charlotte, North Carolina, metropolitan region. The genesis of the effort, Congestion Avoidance and Reduction for Autos and Trucks (CARAT) is described as an outgrowth of concerns about increasing traffic congestion in several wedges of the metropolitan area. The paper then describes the steps taken to develop the CARAT concept, increase community support and involvement in its evolution, secure funding, evaluate alternative technologies, and conduct preliminary market assessments. The paper ends with a status report on CARAT at the present time.

INITIAL STEPS

To begin the process of reviewing IVHS technologies, the lead in the Charlotte metropolitan region was taken by the University of North Carolina at Charlotte. The university's goal was to encourage the community to evaluate carefully the potential for IVHS technology in the region and to reach a consensus concerning whether such technology should be explored and adopted. In March 1990, the university hosted a well-attended lecture by a General Motors executive on "Smart Vehicles." This was followed in April 1990 by a workshop attended by about 40 analysts to explore the opportunities further (*8*). In the summer of 1990, a lecture was given by Daimler-Benz (DB) executives working on the Prometheus project in conjunction with Freightliner Corporation, a local DB subsidiary.

The overall conclusion of these discussions was that Charlotte and the surrounding 100-mi region (Figure 1) have a number of attractive features to develop an IVHS demonstration:

- The road system is well suited to large IVHS demonstrations, particularly two crossing Interstates, multiple-path commuting corridors, and a basically radial street pattern. Travelers in the region cannot avoid congestion.
- Traffic congestion is significant and pervasive. The Charlotte region was initially projected by FHWA as the nation's No. 1 city for congestion in the year 2000 (*9*). Even though this forecast has since been discounted (*10*), congestion is still a problem. In particular, the southeast portion of the city has no crosstown circumferential routes; radial routes are congested and outmoded. These are under improvement, and the numerous parallel streets allow for route diversion tests during construction.
- A strong trucking and shipping presence ensures private-sector involvement. Charlotte is a major distribution center, and over 185 trucking companies, 2 major railroads, and numerous shippers and distributors have operations there.
- Numerous agencies and corporations are involved in preparing the proposal and are interested in the CARAT demonstration. These include communications developers and suppliers, computer companies, truck manufacturers and operators, chambers of commerce, electronics companies, and shippers.
- The government, particularly the city of Charlotte, Mecklenburg County, the North Carolina Department of Transportation (NCDOT), and the Carolinas Transportation Compact, is active and interested. The Carolina Transportation Compact is a 13-county organization of elected officials whose mission is to advocate the transportation needs of the region. The city of Charlotte has recently installed a modern traffic-signal coordination system that could form a key part of the in-road traffic detection system.
- Test sites are good, particularly the Charlotte Motor Speedway, the Independence Boulevard Corridor (a major congested arterial undergoing rehabilitation and reconstruction), several reversible lane sections, a number of integrated signal systems, and Interstates 85 and 77.
- The metropolitan region, in many ways a good microcosm of medium-sized U.S. cities, contains over 500,000 people in Charlotte proper, 1.6 million in a 50-mi radius, and over 5 million within 100 mi (Figure 1). The region is large, and development is spread quite thinly throughout the area, generating strong long-distance radial commute patterns overlaid on dense local traffic patterns.
- The area contains the University of North Carolina at Charlotte, a full-service institution with advanced degree programs in engineering, business, and numerous other technical subjects, and a high-tech industrial research park. The university's new Applied Research Center and its Ben Craig Business Incubator Center provide ideal homes for necessary research and development.

COMMUNITY SUPPORT

Early in the review of IVHS technology, the analysts recognized that a successful project would require strong cooperative effort from government, businesses, agencies, and the university. The university is not a manager, operator, or constructor of transportation systems. Therefore, responsibility for the development and implementation of CARAT would need to lie with some other organizational entity. The question of how to develop such an entity and encourage it to "own" the CARAT proposal was seen as critical to the project.

Therefore, CARAT was developed as a cooperative effort among government, businesses, the university, and others. Among the major actors are likely to be the city of Charlotte, Mecklenburg County, surrounding cities and counties, communications and electronics companies, truckers, vehicle manufacturers, shippers, the university, the state of North Carolina, other agencies, chambers of commerce, trade organizations, and, of course, appointed and elected officials.

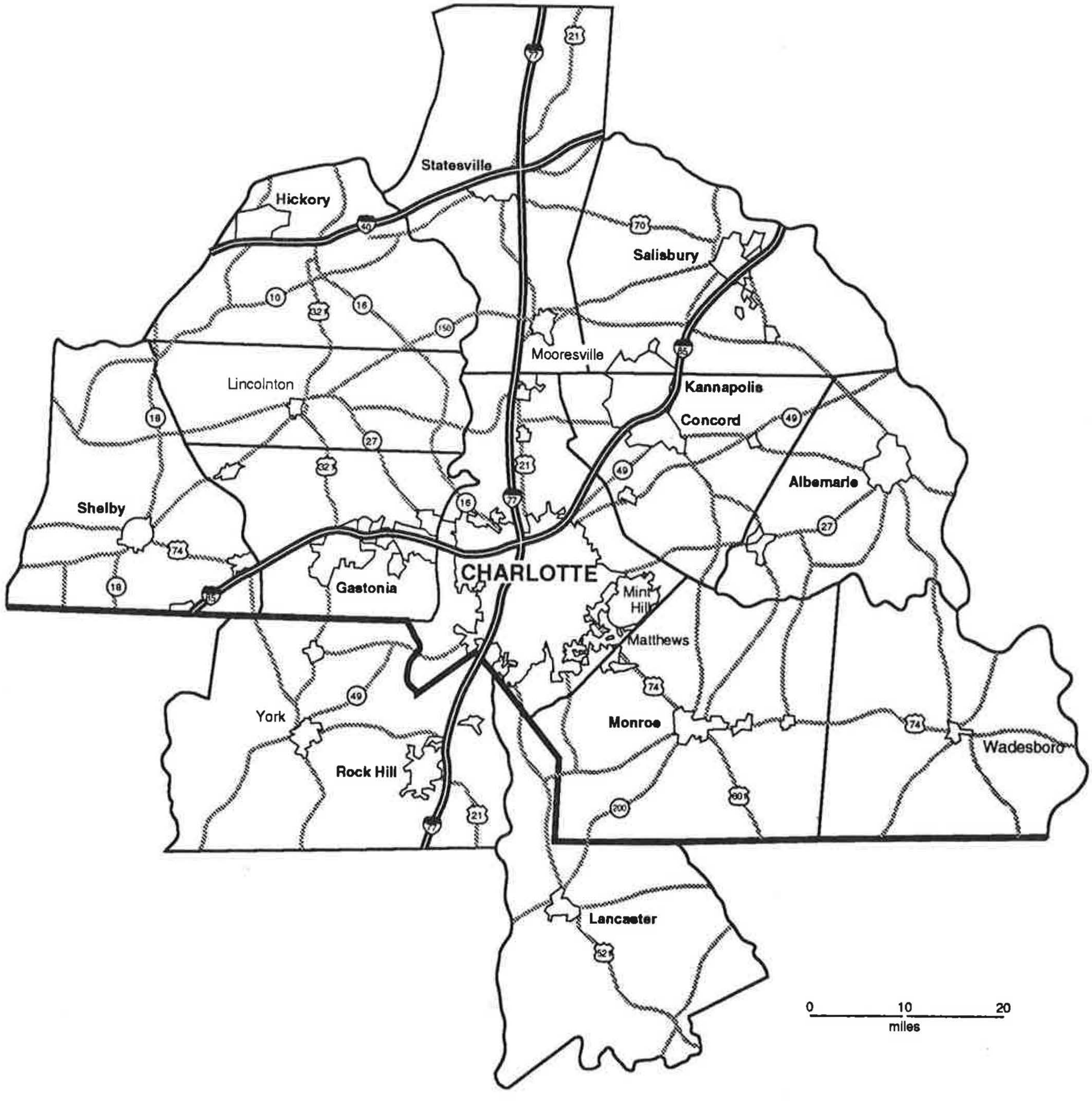

FIGURE 1 Charlotte, North Carolina, region.

Among the organization now regularly attending CARAT meetings are Alltel Mobile (mobile communications); American Automobile Assoc. (travel services); Ben Craig Center (University business incubator center); Carolina Freight (trucking); Charlotte Coliseum (fixed-site operator); Charlotte Convention and Visitors Bureau; Charlotte Department of Transportation; Charlotte/Douglas International Airport; Charlotte Emergency Medical Service; Charlotte Fire Department; Charlotte/Mecklenburg Chamber of Commerce; Charlotte Motor Speedway (race-test track); Charlotte Police Department; ESRI (GIS systems); Federal Highway Administration; Freightliner Corp. (truck manufacturer); Governor's Highway Safety Program; Harris Teeter, Inc. (large grocery chain); IBM; ITRE (state transportation research agency); Intergraph Corp. (GIS systems); JHK & Associates (consultants); Kimley-Horn (consultants); Moss Trucking Company (trucking); North Carolina Department of Transportation; North Carolina State Senate (elected officials); Parson Brinkerhoff (consultants); Sandoz Chemical Company; Scientex Corp. (consultant); Southern Bell Corp. (telecommunications); Southeastern Freight Corp. (trucking); UNC Charlotte, departments of Civil Engineering, Marketing, Geography, and Psychology; and UNC Charlotte Urban Institute (policy group).

To manage the development process, the university has organized a CARAT working group consisting of numerous organizations throughout the metropolitan region and other interested agencies and companies. The membership of the working group has been left open purposely with organizations being added on a steady basis. Initially the purpose of the working group was to assist in the development of an appropriate design for IVHS service for the metropolitan region. More important, the aim of the working group was to develop a community consensus on what the region needs and a sense of ownership by the region for the concept. Particular care was taken to include members of the media, other similar services and systems such as mobile phone companies and telecommunication organizations, and a number of elected and appointed officials. To encourage general awareness of the proposal, reports were developed for use in local newspapers, television, and radio. These reports emphasized the exploratory nature of the effort but encouraged the community to learn about "smart car" technology and how it might affect the region.

Particularly important participants in this study are the Charlotte Department of Transportation and NCDOT. Strong positive support and participation by these two organizations is viewed as absolutely critical to the ultimate success of the concept. In fact, the project will die if these organizations are not in strong support of the concept or are reticent to encourage its study. To develop interest in the project and an awareness of the study, analysts from the state and city transportation departments met with university organizers to express their interest in the effort and to suggest ways by which the project could be adapted to meet their concerns.

DESCRIPTION OF THE CARAT CONCEPT

Overview

The community support activities and learning process described permitted the development of a draft preproposal describing a suggested system for the Charlotte metropolitan region. The following description is for the ATIS portion of the CARAT concept. A parallel ATMS portion by NCDOT is now in the concept stage.

The ATIS portion of the system is envisioned as a multiagency operation—a sort of command center—that would gather data on the highway system from many sources on a continuing basis and package and provide that information to subscribers. Ideally the service would be self-sustaining financially, combining subscriptions with advertising and other revenues. Figure 2 shows the overall structure.

The central "command center" would gather and process information from a variety of sources on the status of the road network. The job of the command center would be to package the information for users and transmit it to them in real time. Key sources of information would include air surveillance via planes and helicopters; truck and delivery vehicle radio; selected field cameras; commuters, through cellular telephones; in-road traffic detectors; police, service, and emergency vehicles; and some fixed-site monitors, such as businesses and towers.

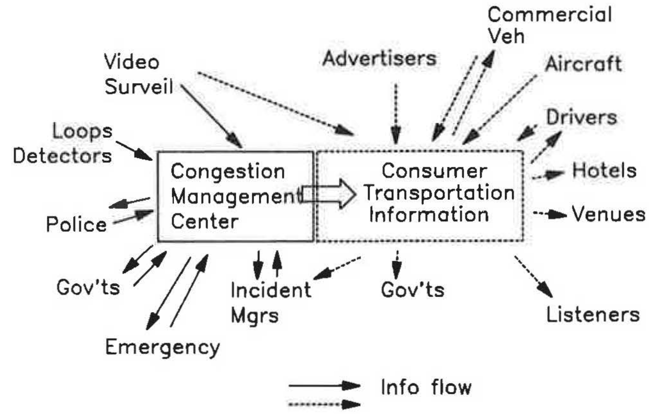

FIGURE 2 CARAT operation.

The information would come in to the command center in a variety of forms, including automated data retrieval, verbal messages, and visual signals. The information collected would consist of traffic and road situation information deemed of interest to the subscribers. An initial list would include traffic congestion at intersections, freeways, and arterials; accidents and tie-ups; fires, crimes, and other emergency events; major community or sports/concert events; average speeds; road construction and utility work; location of free-flowing routes; anticipated delay times; best route options; specialized advertising; and special services or sales by businesses.

As the data flowed in, they would be entered on regional digitized road maps in a form suitable for summarizing by area, "windowing" for transmission to moving vehicles in map or other form or "routing" data for use in congestion avoidance. A regional geographic information system (GIS) such as that being developed at UNC Charlotte would be used for information storage.

Packaged data would be delivered in a variety of ways, including home and office phones, cellular phones in cars, low-band subscriber radios in vehicles, two-way radios in vehicles, on-board maps or other digitized forms, subscriber and cable TV, closed-circuit TV, office announcement systems, drive-by electronic messages, and local-station network TV.

Users would include individual subscribers, trucking and delivery companies, shippers, police and other emergency service agencies, departments of transportation, the media, and distributors. Individual subscribers could receive messages prepackaged by route or location in whatever form is suitable for their needs. As an example, an individual subscriber might elect to purchase the "route congestion service" by telephone. The subscriber would provide the system with data on the normal or usual trip to and from work, including origin and destination, departure times, routes usually taken, and carpool names. Each morning, the subscriber would call the service and be recognized by an incoming number. The service would have prepackaged data for the subscriber in its files by recording all events on the subscriber's path. Information given would then consist of real-time monitoring of intersection delays and an "exception report" noting tie-ups on the route, incidents, other on-going events, and so forth. The data could be given in audio form or hard-copy readout, either at home, office, or on board the vehicle. Essentially, the system would provide a personalized route-planning service, updated continuously but activated only when contacted by the client. As technology advances, the telephone could be replaced by some kind of on-board map such as that developed for Pathfinder, but this is not necessary for initial operation.

As another example, over-the-road trucking companies might also supply the system with data from radio reports and events in and around the region, as far away as 100 mi. As trucks approached the region, the command center could supply directions on routing to avoid congestion, locations for fuel and other stops, and off-Interstate routes for local deliveries. Participating companies would be able to tailor the information to their own needs, rather than attempt to gather and report it on their own, as is common now.

For incident management, an emergency response company might subscribe to data on police and fire or crime calls by location, as well as best-route data from basing locations to the event site and the event site to area hospitals. Presently, some companies compile and make such data available in partial form; these companies might wish to participate in or provide some of the component services for CARAT.

Large fixed-site operators might use the system to direct patrons to use certain routes or park at selected sites for venues. Costs could be added to ticket prices.

The region could also serve as a test site for crash avoidance and other on-board vehicle control technology as it develops. The Charlotte Motor Speedway, a 1.8-mi NASCAR track with high-speed banked turns, might be used for vehicle control and guidance tests before road tests are tried. Since over one-half of all congestion is caused by incidents, many of which are accident-related (*11*), the ability to avoid accidents is a key element in the ability to reduce congestion.

System Benefits

Systems such as CARAT provide a significant opportunity to reduce traffic congestion in medium-sized cities. Among the probable benefits of a comprehensive congestion reduction program would be

- Reduced accident rates and savings in accident costs;
- Savings in travel time;
- Reductions in vehicle operating costs, fuel use, and air pollution;
- Increases in trucking productivity;
- Better, more effective use of the existing street system and a possible savings in future road construction;
- Increased attractiveness for jobs and living; and
- A higher overall regional quality of life.

The exact amount of benefits derived would be a function of adoption, usage, and the impact of a particular technology, but clearly general-use systems would have greater impact than limited-market services (*6,7*). With today's high road-construction costs, benefits such as these can quickly offset the relatively small cost of the study. Construction of 1 mi of freeway in an urban area can easily cost $20 million to $40 million; if the CARAT demonstration leads to a reduction in construction of just 1 mi, its costs will be recouped many times over.

Incremental Phasing

Because CARAT is a complex service, it is not possible to plan, design, and implement the systems in one phase. Rather, implementation is envisioned as taking place over several years. In the early years, work will concentrate on maximizing existing technology by implementing middle-tech solutions that can provide benefits in the short run. Examples include telephone- and radio-based communications systems, coordinated emergency services, and audio response and data gathering. Figure 3 shows an example of some systems that might be included in this first phase. In later phases, services will plan and integrate more advanced high-tech solutions such as tying into in-road traffic detectors, on-board digitized maps, automated vehicle communications, and crash avoidance systems. Most in-road detectors, at signals for instance, could be used to feed the command center on data about traffic density and congestion. Newer technologies under development are expected to improve this capability in the near future. Similarly, on-board maps are available but are essentially still experimental. These maps would be added to the system when their use is perfected.

Organizational Structure

In the start-up years, it is envisioned that CARAT would be developed and operated by a private nonprofit entity, perhaps structured as a "business incubator company." In its initial years the company would have organizational and structural support from the university. As the organization grows, a different, perhaps fully private, structure could evolve.

In summary, the CARAT concept is different from other IVHS concepts in a number of very important ways.

1. It proposes a comprehensive solution to the traffic issues of most metropolitan cities large and small, rather than a specialized solution for particular markets in just large cities.
2. It uses existing available middle-tech technology rather than futuristic high-tech solutions.
3. It proposes incremental development starting with most easily implemented technologies first, adding features later.
4. It relies heavily on the private sector to drive the process.
5. It proposes the use of advertising and subscriptions to offset costs.

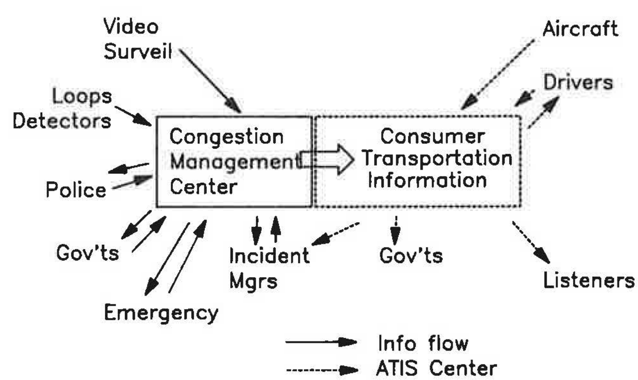

FIGURE 3 CARAT operation: initial phase.

6. It proposes the use of a multiagency command center that would manage the graphical information systems provided by the service.
7. It can be implemented at a reasonable cost.

Costs of Development

Estimates of the cost to develop and operate a CARAT system are presently in preparation. The multiyear program is proposed to ensure continuity and progressive building toward a full working system. Short-range systems planning will not produce the results needed for convincing demonstrations of applicability.

An important element of the evaluation is advertising. It is envisioned that services would be provided along with advertising within the communication channel as a means to increase the revenues to the managing agency and to encourage subscribers to obtain additional useful information about community services and products. It is expected that advertisers themselves would also contribute, thereby reducing the cost to subscribers. It is hoped that revenues through advertising and subscriptions will pay for the system, enabling it to be self-sufficient. For the immediate term, we have been modest in our expectations about the magnitude of potential revenues.

DEVELOPMENT OF THE FULL PROPOSAL

Structure

Efforts to develop the proposal necessary to describe the CARAT study in full detail are under way. NCDOT's involvement in the project has increased, particularly in the development of the parallel ATIS component of CARAT. The tasks involved in preparing the full proposal are as follows:

1. Organizational—the CARAT task force has been expanded and structured to target specific services intended to provide for the needs of different client groups.
2. Data gathering—the study team will prepare a review of IVHS technologies presently under way, assess the circumstances surrounding the Charlotte metropolitan region, and conduct a marketing study to evaluate the demand potential for IVHS technologies in the Charlotte area.
3. Component description—specific IVHS proposals will be described and evaluated extensively. Numerous elements of the proposal will be assessed and an integrated set of components will be developed.
4. Consolidation of elements—numerous IVHS technologies share common requirements. For instance, many technologies require the existence of an electronic or digitized mapping system describing the features of the urban region and highway network. Communication devices that transmit information to vehicles from a central point are another common element of many systems. The CARAT proposal will identify such common elements among the various systems and develop specifications for their use.
5. System description—the various elements of the proposed IVHS system for the Charlotte region, with all of its components, will be identified in detail. The description would include a discussion of how the elements work together, as well as organization structure, timing for implementation, and a plan for evaluation.
6. Preparation of proposal—the preceding materials will be organized into a formal proposal necessary for submission to appropriate organizations for potential funding.

Major Potential Markets

Working with its initial task force committee members, the CARAT study team has identified four markets likely to be most affected by IVHS technologies in the Charlotte metropolitan region:

1. Consumers, particularly commuters in selected high-density and high-congestion corridors in the region, are likely to be affected. There are approximately three such corridors, each of which contains several major commuter streets and freeways.
2. Charlotte is a major warehouse and distribution hub for the southeast and has many trucking organizations and distribution companies likely to be affected. Services provided to these companies might include routing, congestion, incident management, scheduling, delivery and pickup.
3. Several major arterials in the Charlotte region operate in a congested fashion on a continual basis. These arterials are particularly vulnerable to reduction in capacity by emergencies and other incidents.
4. Major hotel and motel operators, coliseums and amusement facilities, parks and lakes, shopping malls, and major employers all need information related to traffic congestion and routing in and around their locations.

Within each of these component areas, the study team has begun to evaluate what services are needed and how they might be organized and funded. The next step of the process will be to evaluate these services with the goal of selecting a smaller number of survivors, that is, the services which pass the feasibility (market versus cost) screen and can be financed.

Market Survey

A particularly important element of the CARAT study is the conduct of an accurate market survey to gauge the potential for different services in each of the four component areas. To undertake this effort, the university has designed a four-part market study concentrating on each of the preceding groups. In each group, representative members will be interviewed by telephone concerning the need for the service, its features, willingness to pay, and overall value compared with other services. The output of the market study analysis will be an estimate of the potential demand for different services at various price levels. Sampling rates for the consumer segment will be designed to yield about 500 completed market responses drawn from the metropolitan region, focusing on

Mecklenburg County and the city of Charlotte. For the other components, the universe of respondents is finite and generally less than 300 members. Therefore, a more extensive sampling effort will be undertaken with sampling rates somewhere in the 30 to 40 percent range. Preliminary market findings show that about 15 percent of consumers would use a general congestion avoidance system at a price of $12 per month.

Evaluation

The CARAT services, if implemented, would not necessarily lead to significant changes in travel patterns or in consumer acceptance. To evaluate the overall effectiveness of this service, it is anticipated that a carefully structured statistical design will be used. The initial design will be a before-after study with a test group and control group. These designs are common in the social services (*12*) and take the following form:

$$\frac{\text{test } O_1 \; XO_2}{\text{control } O_3 \; O_4}$$

where O's are "observations" of behavior, and X is the "treatment," in this case the IVHS service. Tests for X's effect are made by determining the significance of the "difference in the differences," for example:

$$t = \frac{(\overline{O}_1 - O_2) - (\overline{O}_3 - O_4)}{\frac{1}{n}\sqrt{S_1^2 + S_2^2 + S_3^2 + S_4^2}}$$

A number of studies in transportation (*13*) have used these designs to isolate the effect of targeted services.

In this manner, both the internal (intraservice) and external validity of the treatment can be estimated. Internal evaluations using such data as number of inquiries, number of consumers and subscribers, revenues, costs, and operational features will also be maintained, but these alone will not allow for a complete evaluation of the external effectiveness of the system. An analogy may be drawn to the carpool programs in common use around the country. These programs have extensive records on internal activities, such as telephone calls received, inquires made, list provided, and so forth, but very few of them have hard data on the actual number of carpools formed or the effect of those carpools on regional vehicle miles traveled. A quasi-experimental design that would permit the evaluation of this type of program is extremely rare in transportation studies; they need to be developed more extensively.

NEXT STEPS

The full CARAT proposal is expected to be prepared during spring 1992. It will detail additional issues that must be resolved before the project can be undertaken, including

1. Organizational structure,
2. Specifics on kinds of services to be offered,
3. Revenues and costs,
4. Financing,
5. Timing,
6. Public/private partnership and mix, and
7. Implementation plan.

In summary, initial efforts are well under way to develop the CARAT proposal as the first major effort to implement a general-use IVHS system in a medium-sized metropolitan region.

REFERENCES

1. *Discussion Paper on Intelligent Vehicle-Highway Systems*, Department of Transportation, May 1989.
2. Radar Control Systems. *Vehicle Radar* (videotape). July 1990.
3. J. F. Gabard. CALIF: An Adaptive Strategy. *INRETS Review*, Dec. 1990.
4. Operation Tests and Research Activities. *Intelligent Vehicle Highway System (IVHS) Projects in the United States*, FHWA, March 1991.
5. Senate Bill S. 965. IVHS language. May 1991.
6. U.S. General Accounting Office, *Smart Highways: An Assessment of the Potential To Improve Travel*. May 1991.
7. E. Bruce and D. Hartgen. IVHS: How Much Can It Really Help? Presented at Symposium on Vehicle Information Systems, Ann Arbor, Mich., Oct. 1991.
8. *Smart Vehicles and Roads for Charlotte*. Report 38, Transportation Academy, UNC Charlotte, April 1991.
9. J. A. Lindley. Urban Freeway Congestion: Qualification of the Problem and Effectiveness of Potential Solutions. *ITE Journal*, Jan. 1987, pp. 27–32.
10. T. Lomax et al. *Impact of Declining Mobility in Major, Texas and Other U.S. Cities*. Report 431-1F. Texas Transportation Institute, College Station, Tex., 1988.
11. U.S. General Accounting Office. *Traffic Congestion: Trends, Measures, and Effects*. 1989.
12. D. T. Campbell and J. C. Stanely. *Experimental and Quasi Experimental Designs for Research*. Rand McNally, 1963.
13. J. Brusno and D. T. Hartgen. Statistical Controls in Ridesharing Demonstration Programs. In *Transportation Research Record 914*, TRB, National Research Council, Washington, D.C., 1982.

Publication of this paper sponsored by Committee on Transportation System Management.