Abridgment

California INRAD Project: Demonstration of Low-Power Inductive Loop Radio Technology for Use in Traffic Operations

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Interest is growing at both the national and international level in using new technologies to alleviate congestion. The INRAD project examines one set of small-scale technologies working toward an incremental solution to improving the operation of the existing road network. The system uses loop detectors, originally installed in roadway pavement to perform standard vehicle detection, as antennas to exchange information between specially equipped vehicles and a traffic operations center (TOC). Two-way communication is performed using short message exchanges that can be updated from the TOC and the vehicle in real time.

In light of an anticipated increase in current highway congestion levels, new technologies are being sought for use in transportation to significantly improve the efficiency of existing and future highway facilities. The INRAD (Inductive Loop Radio) project at California Polytechnic State University (Cal Poly), San Luis Obispo, investigates the feasibility of incorporating existing sensor, computer, and communication technologies with the present highway system to provide two-way communication between the roadway and vehicles. INRAD has been developed in a manner that requires minor infrastructure changes and creates little disruption to the system.

Two-way vehicle-to-roadway communication is necessary in all intelligent vehicle-highway system IVHS concepts, including advanced traveler information systems (ATISs), advanced traffic management systems (ATMSs), and automatic vehicle control systems (AVCSs). Alternative technologies are being researched to provide this two-way communication. Network design standards must be developed before individual roadway-to-vehicle communication technologies can be effectively evaluated. Design standards will include specifications on the speed and volume of data transmission, one- or two-way communication requirements, and desired functions of the communication system. An effective way to develop such standards is through demonstration projects that reveal some of the networking and logistics intricacies and the potential of the technology being proposed.

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In the INRAD project, messages are transferred when an equipped car passes over an inductive loop. The nature of the transmission technology, low-frequency radio waves over short inductive loops (used as antennas), will allow limited information exchange. The system design is not complicated by massive data transfers to and from the traffic operations center (TOC), and little additional load is placed on the network already operating for traffic detection purposes. The negative aspect, however, is that limited space on the channel of communication between the vehicles and the roadway constrains the kind of information exchanges that can occur.

Driver information and navigation systems have been developed in recent years and are becoming commercially available. However, the INRAD project is one of the few systems attempting to provide real-time, two-way communication between vehicles and a centralized control center. The Road/Automobile Communication System (RACS) (*1*), which is being developed in Japan, uses microwave technology to give drivers location and real-time traffic information. This is done through an infrastructure of roadside beacons, on-board devices, and a central facility. Advantages of this system include high broadcast speed, reasonable cost, and possible two-way communication.

ALI-SCOUT, a European project, uses infrared transmitters and receivers to link on-board displays with roadside beacons that are linked to a central control facility. This system was designed to be capable of two-way communication; however, it is not apparent that drivers can select and send information of their choice to the control center. Infrared communication provides very high transmission rates (between 0.5 and 1 M/sec). This system also requires optical connectivity for transmitters mounted on traffic lights and overpasses to send route guidance information to properly equipped vehicles (*2,3*).

DEMONSTRATION AND RESULTS

In March 1992, the first inductive radio demonstration was held in Los Angeles, California. The demonstration was designed to evaluate the effectiveness of two-way short-range radio communications between vehicles and the roadway. Participants of the demonstration were able to view the operation of the TOC as it communicated with vehicles traveling on the freeway. They were also allowed to road test an INRAD-equipped vehicle to experience the process of receiving and sending messages via the in-vehicle display. Information exchanges were recorded on disk in order to evaluate the feasibility of the applications suggested in the last part of the paper.

The two problem areas that surfaced as needing more development efforts are information management and TOC design. More sophisticated integration of the different components is needed, and the central control computer interface needs to be made more flexible. Overall, the project successfully demonstrated the potential of inductive radio technology in supplying two-way vehicle-to-road communication.

SYSTEM COMPONENTS

The INRAD project included designing and developing electronic hardware and software to support radio communications and highway operations. INRAD software and hardware are divided into four components (Figure 1) that work together communicating through radio transmissions or telephone lines.

In-Vehicle Components

The hardware in test vehicles includes an on-board computer, a liquid crystal display (LCD), and an antenna. The function

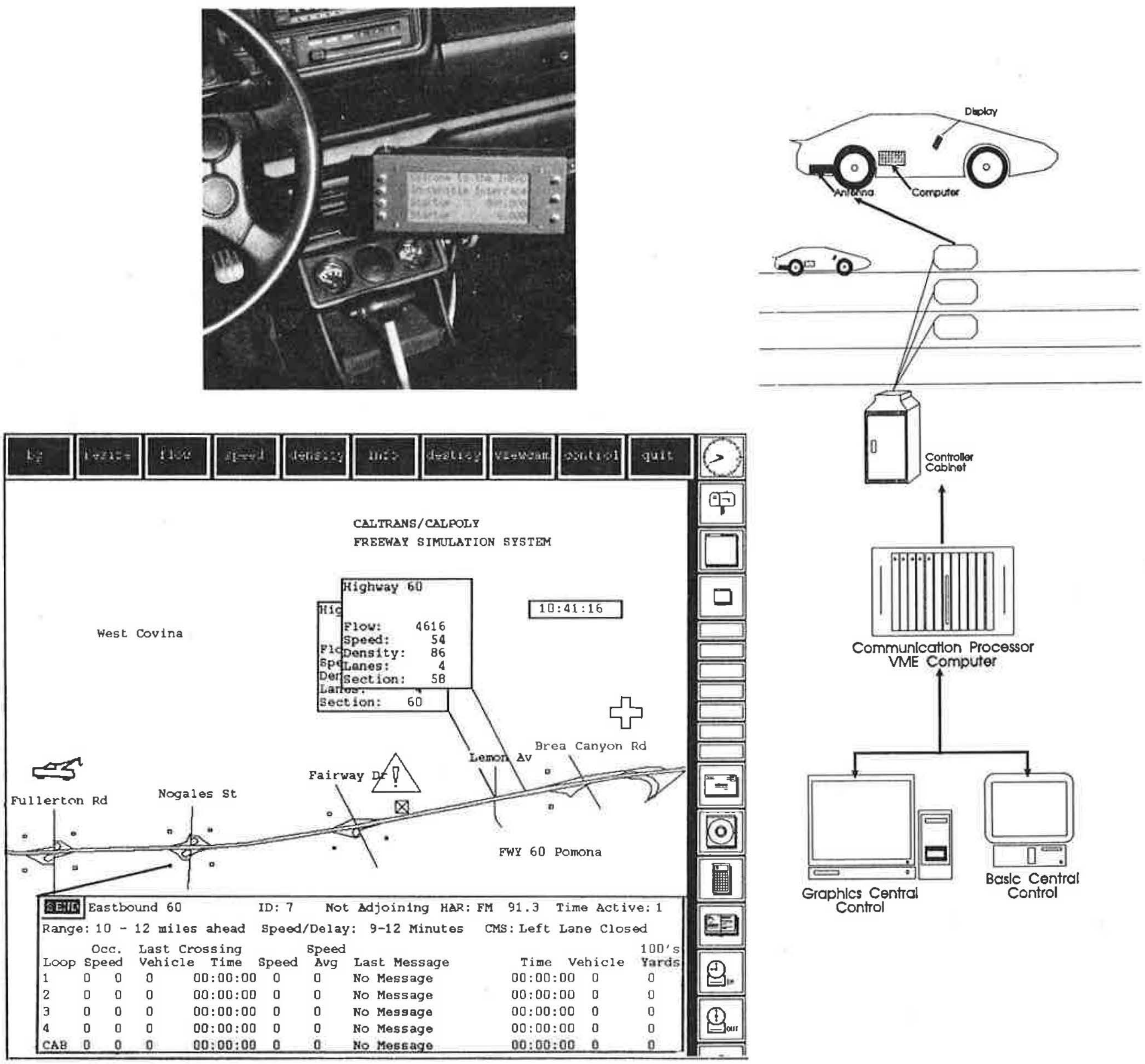

FIGURE 1 Components of INRAD.

of the computer is to post, on the display, messages received from the TOC and to enter messages sent to the TOC. The computer is connected to a radio transceiver that is attached to the rear bumper of the vehicle. The limited-range radio transceiver is able to communicate simple messages to and from an inductive loop as the vehicle crosses the loop. The messages are sent in the form of 6-byte digital code at a frequency of 375 kHz. Serial data are transferred at rates up to 9,600 baud (bit/sec). The system will allow one code to be transmitted in each direction at each loop crossing.

In-Cabinet Components

The roadside cabinets are equipped with a computer using an industry-standard STD bus. This computer controls the transmission of radio messages between vehicles and the communications processor (CP). The STD system uses a 2,400-baud phone line to communicate with the CP located at a central location.

Communications Processor

The CP is a VME bus computer that runs the OS-9 operating system. This computer manages all communication between the controllers and the central computers and distributes all the messages to their correct station. The CP also records all communication between the central control computers and the STD computers on disk or tape.

Central Control Computers

The central control (CC) computers allow the TOC operator to communicate with INRAD-equipped vehicles and monitor traffic data. Two different versions of CC computers have been developed. The first is the basic control computer (BCC) and is a PC system running the MS-DOS operating system. This version provides an inexpensive and simple screen-based user interface. The BCC had four display screens, which show all incoming and outgoing messages and the current average speed and occupancy of each section of highway. Another function of the BCC is to automatically analyze traffic data in order to issue speed and congestion warnings.

The second version of CC computers is the graphic control computer (GCC). This is a Sun workstation running the Unix operating system under the X Windows environment, which provides a sophisticated, user-friendly graphical interface operated with the keyboard and mouse device. The GCC displays INRAD loop and vehicle icons on a pictorial map of the freeway. All the information in the BCC can also be accessed by the GCC. The two CC computers can communicate with the CP via direct cables or, for longer distances, 2,400-baud telephone lines.

INRAD APPLICATIONS

The INRAD system has been designed to maximize the hardware and software capability and flexibility to send and receive pertinent real-time information to and from INRAD-equipped vehicles and the TOC or other central control facility. The user groups benefitted by the system would include commuters, highway maintenance crews, emergency services, transit and taxi services, commercial freight services, and private delivery firms. Possible uses are described in the following section.

Commercial Fleets

Commercial fleet use is an example of INRAD's automatic vehicle identification and location (AVI/AVL) capabilities. INRAD-equipped buses would automatically send identification and location information to central control each time they pass over an inductive loop. This allows central control to track the bus graphically, providing accurate, real-time monitoring of the bus fleet. A printout would also be produced at the central control site showing vehicle identification, location, date, time of day, and messages being transmitted or received. Included in the automatically generated information from the vehicle is space devoted to a message selected by the driver from menu items on the in-vehicle display. The driver could inform central control of remaining capacity, request emergency services, or receive new instructions from cental control.

The tracking and two-way communication provided by INRAD allow fleet controllers to make more demand responsive decisions. This type of technology can be tailored to benefit many various delivery services, local transit, and car rental companies.

Advisory System

Advisory system use would apply INRAD as a simple means of alerting drivers to various driving conditions ahead. Using INRAD as an advisory system provides real-time and very specific information on the immediate section of freeway being traveled. Advisory systems have proven to be effective in reducing accidents and congestion. The following alerts were successfully transmitted in the March 1992 INRAD demonstration.

HAR Alert

The most general alert is the highway advisory radio (HAR) alert. Drivers of INRAD-equipped vehicles could be alerted to the HAR alert by an audible "beep" when they pass over an inductive loop. The driver would then receive an alphanumeric message on the in-vehicle display; the message would advise the driver to tune the radio to a specific radio frequency on which is broadcast more detailed information about the section of freeway on which the driver is traveling or entering. The information may include details about freeway construction, fires, accidents, or other extraordinary conditions. The on-board interface uses the top two lines of the 20-character by four-line display panel. The lines read

DETAILED INFO ON HAR
TUNE TO *XX YYYYY*

where *XX* is either AM or FM and *YYYYY* is the frequency.

Speed-Decrease-Ahead Warning

Another advisory alert is the speed-decrease-ahead warning, which alerts drivers to a significant speed decrease in the next freeway section. The average speed at each set of loops is automatically determined and forwarded to the upstream loops by the BCC. The upstream loops then transmit this information to INRAD-equipped vehicles as they pass. A computer hookup to the speedometer in the vehicle records the vehicle's current speed and compares it to the speed of the next section. If the current speed is substantially higher than the average speed at the next set of loops, the driver is warned by a beep and a message. This gives the driver additional time to slow down and is particularly useful when adverse weather conditions impair vision.

The in-vehicle user interface uses the top two lines of the LCD panel. The message relays the following information:

> > > > > ALERT! < < < < <
XX MPH TRAFFIC AHEAD

where *XX* is the speed in the next section. This warning will be overridden only by a congestion-ahead warning.

Congestion-Ahead Warning

This message alerts drivers to delays on their freeway or an adjoining freeway up to 26 mi ahead of their present location. Information from standard loop detectors and current vehicle speeds received by INRAD-equipped vehicles can be analyzed to determine if significant delays are occurring. If so, the driver is alerted and shown the number of miles until congestion is encountered and the expected delay in minutes on the display. This accurate, real-time information about current conditions on the roadway enables drivers to make informed decisions affecting their travel route. The top three lines of the in-vehicle display shows the congestion-ahead warning. This message appears as follows:

AA–BB MINUTE DELAY
CC–DD MILES AHEAD
ON ADJOINING FREEWAY

where *AA–BB* shows the range of probable delay and *CC–DD* shows the range of distance before the congestion occurs.

Freeway Maintenance

The drivers of INRAD-equipped maintenance vehicles could send messages to central control concerning the road condition as they drive. Because the vehicle would be tracked by INRAD, the location where the notes apply would automatically be recorded along with the notes. INRAD can be used to calibrate and fine-tune other system status detection methods (speed calculation through occupancy, video image processing systems, etc.). Eventually, if enough vehicles are equipped with INRAD, it could be an excellent detection method itself.

Freeway Service Patrol

The use of roving service patrols to provide motorist aid is a proven strategy for reducing congestion in urban areas. The effectiveness of these service patrols can be greatly improved with the help of INRAD technology. The system would track service patrol vehicle location and allow for quicker and more efficient dispatching of the most appropriate vehicle to the emergency site. Information on system performance can also be obtained by monitoring the vehicle speeds and travel times of these roving patrol vehicles.

Dynamic Road Pricing

INRAD can be used to allocate user fees properly according to time and mileage on the system. Each vehicle would have its own identification and could be tracked by INRAD, updating a data base accordingly. INRAD could allow for dynamic congestion pricing to encourage drivers towards optimum operating conditions. A message would be posted on the in-vehicle display notifying the driver of a toll increase far enough in advance to allow proper decision making.

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