Real-Time Responses to In-Vehicle Intelligent Vehicle-Highway System Technologies: A European Evaluation

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A gaming and simulation experiment is being conducted in Europe to assess the behavioral impacts of in-vehicle intelligent vehicle-highway system (IVHS) technologies. The experiment is being carried out as part of the EURONETT project under the European DRIVE initiative. It concentrates on real-time responses to in-vehicle driver information systems within an urban environment. A brief overview of the DRIVE program is provided. The objectives and scope of the EURONETT project are described, and the role of simulation and experimentation within EURONETT is explained. The experimental design and methodology are then presented, and the measures of effectiveness being used are described. Finally, the innovative gaming approach being adopted is summarized, and application of the results is considered.

The world of road transportation is undergoing a fundamental change. New technology is being developed at a great rate, which can help motorists, transportation authorities, and fleet operators make better use of their vehicles and the highway network. These advances are particularly important in view of the rising urban congestion levels being experienced worldwide.

The potential of these new technologies and growing concern over road transportation problems have led to a number of research, development, and demonstration initiatives throughout the world. These initiatives include the U.S. intelligent vehicle-highway system (IVHS) program, European programs such as DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe) and PROMETHEUS, and Japanese programs such as RACS and AMTICS. These initiatives embrace a wide range of technologies, such as traffic management and control systems, driver information systems, and automated vehicle control systems.

However, the success of new technologies in improving road transportation will depend on policy makers and industry choosing the most appropriate technology and applying it in a way that will maximize its benefits. Knowledge of the ways in which motorists are likely to respond to different types of technology is required. This crucial issue is being addressed within EURONETT (Evaluating User Responses on New European Transport Technologies), as part of the European DRIVE initiative.

One particular aspect of EURONETT—an experiment to assess real-time behavioral responses to in-vehicle driver information systems—is addressed. This experiment covers responses to on-board navigation aids, dynamic route guidance systems, and the radio data system traffic message channel (RDS-TMC) traffic information broadcasting system. Following an introduction to DRIVE and EURONETT, a description of the innovative experimental methodology being used and the measures of effectiveness being recorded are provided. Application of the experimental results is then considered, and conclusions on the work being carried out in this vital area are presented.

DRIVE

The DRIVE program is a $140 million research program of the Commission of the European Communities (CEC), linking information technology and transportation. DRIVE was formally adopted as a community research program in June 1988, and 61 cooperative projects were subsequently funded under the first program phase.

DRIVE has three primary objectives, as follows (*1*):

1. Improving road safety,
2. Maximizing road transport efficiency, and
3. Contributing to environmental improvements.

DRIVE envisages a common European road transport environment in which drivers are better informed and intelligent vehicles communicate and cooperate with the road infrastructure itself. The program follows a top-down systems approach to the research and overall design of traffic management and safety systems, which represent a significant advance over those now available.

Specifically, DRIVE aims to achieve the following results:

- Identification of the best choice of systems on the basis of economic, social, and technical criteria;
- Development of optimal strategies for their implementation;
- Specification of performance and compatibility standards that will enable industry to develop the necessary equipment and systems;
- Provision of directives and guidelines to which industrial products and intelligent European road transport infrastructures should conform; and

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- Design and implementation of pilot schemes to assess the performance of equipment and systems.

EURONETT

EURONETT is a 3-year project that lies at the heart of the DRIVE program (2). Its main objective is to assess and predict the behavioral responses of travelers to policy initiatives on the basis of new technology (or the IVHS). Within this framework, it also aims to produce a EURONETT toolbox comprising various models that can be used in the future by transportation authorities in evaluating the likely effects of alternative measures.

EURONETT feeds into many other projects currently in progress, both within DRIVE and in national or local projects taking place in individual European countries. For these projects, it will provide vital data and tools for assessing effects that assume a new importance with the introduction of IVHS technologies. Equally, some of the products of EURONETT will ultimately be applicable to similar investigations in North America and Japan.

The EURONETT project is being undertaken by a consortium of six partners from four countries, including government user organizations, consultants, and universities with relevant expertise. The project consists of six major tasks, which are structured into eight work packages as shown in Figure 1. The major research investigations are concentrated in Work Package 3, whereas Work Packages 5 and 6 involve development of the EURONETT toolbox.

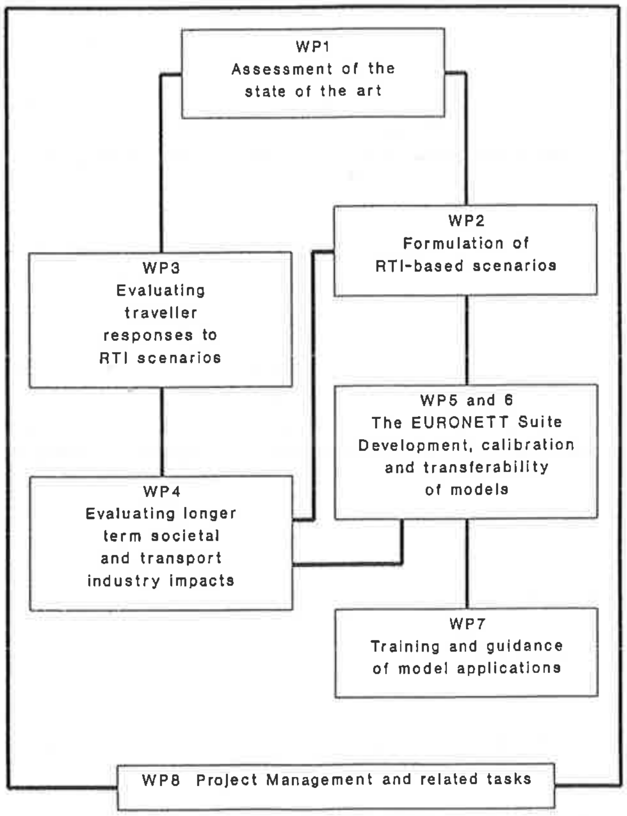


FIGURE 1 EURONETT project structure.

IN-VEHICLE SIMULATION AND GAMING

Within the EURONETT project, much of the research into user responses to new technologies is being conducted using established stated preference techniques. Surveys are in progress using these techniques in two European cities (Athens and Birmingham) to investigate user responses to a range of technologies. These include the following:

- Electronic road pricing systems,
- Improved public transport information systems,
- Advanced integrated traffic control systems, and
- Electronic trip planning services.

These surveys have proved successful in evaluating user reactions; although the technologies themselves may be complex, interactions with system users are relatively straightforward. However, in-vehicle driver information systems often require the driver to make route-choice decisions in real time while undertaking a task (driving) that is itself onerous and demanding. The complexities of this decision-making process are difficult for someone to perceive when removed from the driving environment and presented only with visual stimulus material.

Therefore, to investigate user responses to in-vehicle driver information systems, an alternative approach has been adopted with EURONETT. This approach uses a simulation and gaming technique, which makes the experimental subject act on information provided by these in-vehicle systems in real time. The subject simultaneously performs a task that simulates driving a vehicle through an urban street network to represent the situation that would be encountered in using such systems on the highway.

The main reason for using gaming simulation is to create or re-create decision environments to observe how people assess options and reach decisions in situations that are either familiar or unfamiliar to them. It is the creation of the decision environment that strongly influenced the adopted approach.

The decision environment present in a driver's navigation task was examined, and it was apparent that certain key features of this environment must be included in the simulation, as follows:

- A real-time environment,
- A task of subjective mental workload commensurate with driving,
- A task containing navigational decisions, and
- A task allowing the presentation of driver information conceptually compatible with European road transportation technology initiatives.

After a review of possible ways to create this decision environment, a computer game was selected that fulfills these criteria. However, it was recognized that a validation exercise would need to be included within the experimental framework to ensure that behavior in the simulation trials is similar to real-world driving and navigational behavior. Because of external factors relating to the project, the validation exercise is being undertaken after the main series of simulation trials. It is discussed briefly in a later section.

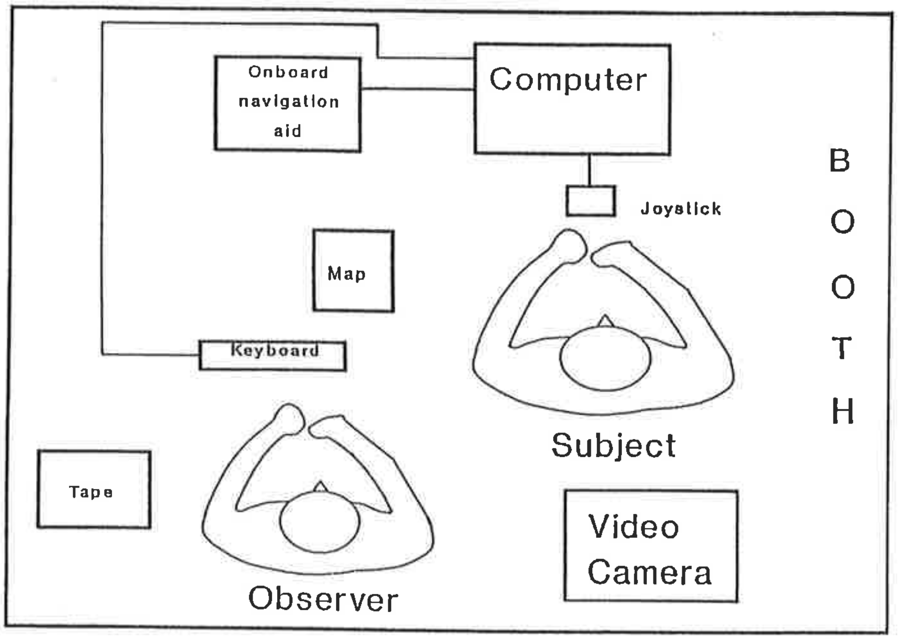


FIGURE 2 Experimental layout.

EXPERIMENTAL TOOLS

The primary objectives of the gaming and simulation work in EURONETT is to get a measure of subjects' route choice decisions in an urban network when provided with different types of in-vehicle driver information systems. The laboratory simulation approach is intended to complement the other approaches being adopted in EURONETT to assess drivers' responses to new IVHS technology.

The experimental design makes use of a commercially available computer game. This game provides a three-dimensional simulation of the San Francisco road network and gives a driver's-eye view of the road ahead and the vehicle controls and gauges. The experimental subject is then able to navigate the vehicle through the network, while being presented with information from different in-vehicle driver information systems.

This computer game was selected as the basis for the simulation and gaming experiment following pilot trials. The software runs on an IBM PC adapted with an enhanced graphics adaptor (EGA) and a joystick interface and card. For the experiments, the software is being used in training mode, which precludes racing or serious accidents.

Control of the subject's car can be overridden from a keyboard so that the car can be slowed by the experimenter. By limiting the driver to first gear, a maximum speed of 40 mph can be achieved. This limit is realistic for the urban environment being used for the experiments. Piloting of the software using young drivers previously unacquainted with the software showed that 10 min is a reasonable training time for subjects to achieve a sufficient level of confidence in controlling the vehicle and avoiding collisions.

The software models the network in three dimensions in real time using EGA color graphics and sound effects. There are various viewing modes. The mode selected for the experiment allows a driver's view through the windshield, giving a good three-dimensional representation of the vehicle gauges and steering wheel and realistic optic flow patterns generated by oncoming roads and passing buildings. The software includes other traffic, such as buses, trucks, ambulances, taxis, motorbikes, and police patrol cars. There are also pedestrians on paths and crossing roads.

The area of the network selected for experimentation starts by the San Francisco Zoo on the southwest side of the city and extends to a gas station one block down from Golden Gate Park. The test network therefore incorporates four distinctive landmarks. The zoo is at the starting point. On the left-hand side, traveling toward Golden Gate Park, is the Pacific Ocean. Next is Golden Gate Park itself, and at the destination there is a gas station. Along the route there are secondary landmarks in the form of differently colored buildings.

During the experiments, the subject sits directly facing the PC screen to the simulation game. Connected to the computer is a joystick, which is fixed in front of the subject. A second screen is located adjacent to the main computer for use in one particular technology scenario. The experimenter is seated out of the subject's line of sight and has a tape recorder and computer keyboard within reach. A video camera is positioned behind and above the subject to get a view over the subject's shoulder so that all key experimental parameters can be recorded. This layout is shown in Figure 2.

EXPERIMENTAL DESIGN

Experimental Procedures

The experiment is essentially a "within-subjects" design. In the first phase being conducted within EURONETT, a relatively small subject sample is being used, with up to 20 experimental participants. The participants have therefore been selected to have similar demographic characteristics, although some initial examination of variation in response by age range is included. In view of the limits on resources available, the intention in this initial experimentation phase is to concentrate on one particular population group: young drivers 17 to 30 years old. Subsequent experimental phases (possibly outside the current EURONETT project) would further investigate variations in response across different demographic groups.

Each experimental subject is given the task of navigating the vehicle to the gas station destination on each of 20 repeat trial runs. At least 12 route-choice decisions must be made on each run. During each run the subject is given different items of information en route to represent one of four technological scenarios (described later). Each subject therefore attempts the journey five times under each scenario, with the order of presentation of the different scenarios being randomized.

Before the trials commence, subjects are given a 15-min period to familiarize themselves with the driving task on a separate part of the network. During this familiarization period, subjects experience congestion and delays and get to see an example of the landmark they are attempting to reach.

Subjects are paid an incentive for participation, with a larger prize offered to ensure sensible participation. Subjects are encouraged to

- Drive safely,
- Drive legally,
- Drive along a sensible route, and
- Drive swiftly.

These criteria are also the ones used to judge the best overall driving performance in awarding the prize.

During the course of each trial, the experimental subject may encounter delays or congestion on the road network. This situation is characterized within the simulation game by an external slowing of the subject's vehicle to 0 to 5 mph for a predetermined duration. Two levels of congestion severity are included within the experimental design, each having a different congestion duration. Congestion patterns across the network are selected randomly by the experimenter from 20 defined patterns before each trial (without the knowledge of the experimental subjects).

At the conclusion of the experiments, subjects are fully debriefed. The experimenter answers any questions the subjects may have. In addition, a short questionnaire is used to elicit subjective impressions of the value of each technology in making navigational decisions.

Technological Scenarios

Four technological scenarios are being investigated within the gaming and simulation strand of EURONETT: one baseline scenario and three scenarios focused on different in-vehicle driver information technologies.

Scenario 1

The baseline scenario represents a normal driving situation, in which a driver has no technological aids to use in navigating around an unfamiliar highway network. Information available to the subject at all times includes a street map of the area, plus the name of the street on which the vehicle is traveling and the cross street being approached. The street name information is provided through a facility on the dash display in the driving simulation game. Information that could normally be gleaned from street signs is given. This minimum level of information is also available to subjects in the other scenarios.

Scenario 2

The second scenario provides the driver with an on-board navigation aid in the form of an in-vehicle electronic map display. A street plan is illustrated on a second small computer screen, and the current position of the subject's car on the network is indicated by a flashing blue mark. This display operates in real time and is constantly available to the driver. The display is located to the side of the driver at a viewing angle that is typically of in-vehicle dash mounting.

Onboard navigation aids (*3*) with electronic map displays are being developed and introduced by a number of manufacturers in Europe and other areas of the world. The additional help they can provide could potentially affect route-choice decisions, justifying their inclusion in the experimental scenarios. Current systems that use some form of locational display include ETAK and the Philips CARIN system.

Scenario 3

The third scenario covers the use of an externally linked route guidance system (*4*). Such systems include electronic route-planning and route-following aids, which have a communications link from in-vehicle guidance equipment to an external system providing real-time network or traffic information. The principal difference between these systems and self-contained electronic map display aids is that they provide actual routing advice to the motorist, which can account for real-time traffic conditions.

In this scenario, a route guidance system is represented that is similar in concept to the AUTOGUIDE and LISB systems being implemented in pilot schemes in London and Berlin, respectively (*5*). These systems use a network of infrared beacons strategically located on the road network, as well as in-vehicle units with an in-built dead-reckoning capability for navigating between beacons. Two-way data communication between the in-vehicle units and the beacons allows information on network conditions to be exchanged between the vehicle and a real-time network condition data base.

In trial runs under this scenario, information is presented to the subject in the form of audio messages at key intersections. These routing advice messages conform to the AUTOGUIDE specification developed for the London pilot scheme. For the trial street network, the messages guide the subject along an optimal or near-optimal route, calculated according to the congestion pattern for that particular trial run. Provided the subject follows the guidance advice, advice is provided at all subsequent key points.

Scenario 4

The fourth scenario provides simulated information from the RDS–TMC. The RDS is a system that enables digitally encoded data to be inaudibly superimposed on the stereo multiplex signal of a conventional FM radio broadcast (*6*). It is currently being widely introduced in Europe and has been chosen as a world standard.

International efforts are taking place to develop standards for the RDS-TMC (*7*). A specialized receiver is required to decode traffic messages, which can then be displayed either as text or as synthesized speech. Such a system is particularly attractive from a European perspective, because digital transmissions can be interpreted in the language of the driver's choice. Studies are also being undertaken in countries outside Europe, including Canada and Hong Kong, to investigate the possibilities of implementing RDS-TMC. In the United States, Chrysler has been carrying out trials of RDS traffic information in the Detroit metropolitan area.

In trial runs under this scenario, a sequence of audio RDS-TMC messages is presented to the subject at the start of each run. These messages conform with standard message formats currently being finalized in Europe and relate to the congestion pattern for that particular trial run. The messages can be repeated on request en route to represent that capability of RDS-TMC receivers.

EXPERIMENTAL MEASURES

There are many measures that could be taken using the experimental design and procedure that have been adopted. However, to keep the analysis within reasonable limits, to maintain direct relevance to the experimental objectives, and to minimize the load placed on the experimenter, only the most important subset was selected.

The measures in this work fall into two categories:

1. Primary measures, and
2. Secondary control measures.

Primary Measures

The primary measures relate directly to route choice decisions made by subjects. These measures were developed by considering the different ways in which each technology aims to improve drivers' navigational decisions. The baseline scenario provides basic information on the street network but no real-time traffic condition information. Scenario 2, with an on-board navigation aid, provides an additional tracking capability but again no real-time information on traffic conditions. Drivers avoiding congestion by using these information sources must therefore do so intuitively.

Scenario 3, involving a route guidance system, provides actual guidance advice on the basis of knowledge of real-time traffic conditions but offers no direct information on the conditions that cause the advice to be given. The effectiveness of the system lies in how often advice from the system is accepted and followed. Conversely, RDS-TMC (Scenario 4) provides information on traffic conditions but no explicit advice on optimum routings. The system works by persuading drivers to avoid congested areas about which messages have been broadcast.

With these considerations in mind, primary experimental measures were included in the experimental design that will provide information on the percentage of drivers who will act on real-time information or advice given (Scenarios 3 and 4) or who will avoid congestion intuitively (Scenarios 1 and 2). This information can then be used as input to route-choice models. These primary measures are as follow:

- *Scenario 1.* Number of times congestion is encountered ÷ number of trials;
- *Scenario 2.* Number of times congestion is encountered ÷ number of trials;
- *Scenario 3.* Number of times routing advice is taken ÷ number of trials; and
- *Scenario 4.* Number of times a subject hits congestion about which there has been an RDS message ÷ number of trials.

A further important primary measure was included within the experimental design to provide a comparison of the quality of route chosen by subjects under each of the technological scenarios. Although route quality is difficult to measure definitively, a measure called route quality index (RQI) was defined for comparison of scenarios. The RQI is based on the difference between a subject's chosen route in each trial and the optimum route for that trial, accounting for the prevailing congestion pattern.

In calculating the RQI and in determining optimum routes, consideration was given to research on drivers' criteria in route selection. This research (*8*) indicates that trip time and trip distance are dominant factors in drivers' route-choice decisions, with trip time being the most important factor. Hence, some balance of these two factors should be used in identifying optimum routes and in judging the quality of routes selected by subjects.

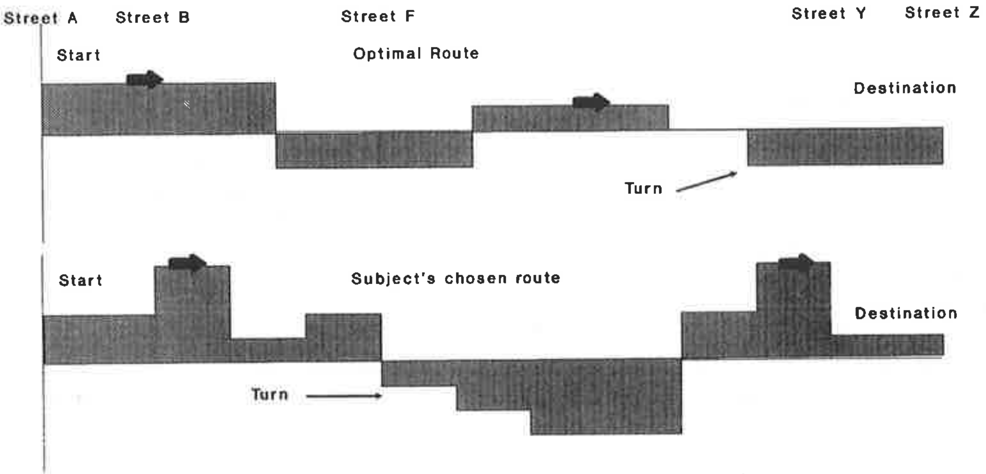
The RQI used in the experiments is therefore a weighted sum of the difference in trip time and the distance between the subject's chosen route and the calculated optimum route, as shown in Figure 3. Route quality is therefore calculated as follows:

$$\text{RQI} = a \times \frac{\text{trip time (chosen} - \text{optimum)}}{\text{trip time (optimum)}} + b \times \frac{\text{trip distance (chosen} - \text{optimum)}}{\text{trip distance (optimum)}}$$

The constants a and b can be varied to reflect the relative importance of each variable in the overall RQI. Using this measure, it follows that the optimum route has an RQI that tends to zero. The value of the RQI becomes progressively more positive as the route progressively deviates from the optimum.

Secondary Measures

The secondary control measures recorded within the experiment are designed to provide feedback on the performance



$$\text{Route Quality Index (RQI)} = a \times \frac{\text{trip time (chosen - optimal)}}{\text{trip time (optimal)}} + b \times \frac{\text{trip distance (chosen - optimal)}}{\text{trip distance (optimal)}}$$

FIGURE 3 Measurement of route quality.

of the experimental design. These measures were identified as the most likely to provide explanations of some of the more plausible causes of variance in the final results. They also provide objective measures of subjects' continued serious participation.

The first of these control measures is the time taken by each subject to complete each trial. This time is measured to check for learning effects on the network. If there is a significant decrease in time taken over the trials, then it will be possible to conclude that learning has had a major effect. This measure also helps to indicate whether subjects are treating the experiments as a real-time exercise or are regularly taking time to solve what they perceive as the problem. Finally, this measure taken with any particular congestion pattern provides an index of difficulty for that pattern.

The second control measure is the number of times the map or the onboard navigation aid is scanned. This measure will provide a rough indication of whether subjects really are using the system. Piloting indicated a mismatch between the subjects' verbal reports during debriefing and their actual trial behavior, which is not uncommon in psychological research.

The third control measure is the number of times the RDS messages are requested over the trials. This measure provides a rough indication of whether subjects are using or attemping to use the RDS.

Finally, the number of collisions is recorded. Although most collisions do not affect the progress of the trial run, this measure provides an objective evaluation of the subjects' safe driving. It enables a rough guess as to whether the subjects are (a) competent and (b) taking the experiment seriously.

FUTURE WORK AND APPLICATION OF RESULTS

Once simulation and gaming trials are completed, a full analysis of results will be conducted. These results will provide valuable insight into the behavioral responses of motorists to in-vehicle IVHS technologies, as well as a comparative measure of the value of the each type of technology under test.

On completion of the laboratory-based work, a validation exercise will be undertaken to ensure that the simulation results give a true measure of real-world driver responses. This exercise will use an instrumented vehicle, in which a limited subject sample will be given navigational tasks comparable to those of the simulation experiments. The validation trials will take place on a restricted area of the actual highway network and will encompass each of the technological scenarios.

Within the validation exercise, data will be collected that will allow tests for realism to be conducted. For example, the frequency with which information sources are scanned or requested in the simulations and in the validation trials will be compared. Similarly, glance duration and other measures recorded on video in both sets of trials will be compared.

The results of the simulation experiments will be used to modify and calibrate a route choice model. This model will form part of the EURONETT toolbox, which as a whole will allow the effects of different levels of behavioral response to new technologies to be assessed on the European road transportation system.

The route-choice model will allow a future vehicle fleet to be represented, with different types of technology in various percentages of vehicles. The model can then be used to examine the effects on traffic performance of an incident or congestion occurring on the network. The results of the simulation trials will indicate the rerouting responses for each type of technology within the vehicle fleet, and these responses can then be used to compute overall network effects.

This facility will be valuable for making future policy and planning decisions within the European transportation environment. Application of the model in the United States would also give a powerful tool to transportation agencies and legislators, if U.S. behavioral data could be elicited from a similar experimental program. This is particularly so in view of the IVHS initiatives now gathering momentum in the United States.

SUMMARY

A description has been provided of an experiment currently in progress in Europe to determine behavioral responses to in-vehicle IVHS technologies. The experiment is being undertaken as part of the EURONETT project under the European DRIVE initiative. It uses an innovative PC-based simulation and gaming approach to focus on real-time responses to in-vehicle driver information systems within an urban environment.

The background to DRIVE and EURONETT has been briefly outlined, and the way in which the simulation and gaming work fits in with other EURONETT investigations has been described. Experimental tools and design have been discussed, together with measures being recorded within the investigation. Future work and potential applications have also been outlined.

The technologies being investigated within the experiment include onboard navigation aids, route guidance systems, and the RDS-TMC. These system categories were selected for the following reasons:

- All are in-vehicle driver information systems, which therefore require routing decisions to be made while the normal driving functions are being undertaken; and
- All are almost certain to be in use in the near future in the early stages of a European integrated road transport environment.

The results of the simulation and gaming experiment will be of value in assessing the traffic performance effects of the widespread introduction of these IVHS technologies in congested urban areas. They will permit modification and calibration of route choice models, allowing wide area effects of incidents and congestion with a future IVHS-equipped vehicle fleet to be determined. These models will form powerful tools for transportation agencies in both Europe and the United States allowing IVHS implementation to proceed during the next decade on a fully informed basis.

ACKNOWLEDGMENT

The EURONETT project is being undertaken by a consortium of partners on a cooperative basis. The input of all partners to the project is duly acknowledged.

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