band system might otherwise be preferred, additional processing of the signal in a phase system offers the possibility of significantly increased resolution.

As a final consideration, it would appear that mobile data links will be an integral part of vehicle-location systems. Digital transmission of canned message and status information will permit extremely efficient handling of some forms of applicable routine communications, though such forms can never replace voice communications.

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An Electronic Route-Guidance System for Highway Vehicles

DAN A. ROSEN, FRANK J. MAMMANO, MEMBER, IEEE, AND RINALDO FAVOUT

***Abstract*—The electronic route-guidance system (ERGS) is the result of an effort by the Office of Research and Development, Bureau of Public Roads, to develop a new concept for guiding the motorist. To implement the concept, a system has been developed which makes use of electronic equipment both in the participating vehicles, and at intersections which are to supply guidance instructions. The system is destination oriented. The driver enters a code word, representing his intended destination, into the vehicle equipment. Then as the vehicle approaches each instrumented intersection, the destination code is transmitted to the roadside where it is decoded, according to a stored program, and a routing instruction is transmitted back to the vehicle. In the vehicle, the routing instruction is displayed to the driver in the form of a symbol or word message, which gives the maneuver the driver should make at the upcoming intersection or interchange to reach his destination optimally.**

The development of the system from its conception to its future application and benefits are discussed. The descriptions of today's highway routing problems in the "static" and "dynamic" situations are presented, then the outline of the Bureau of Public Road's developmental effort and the major contributions of its various contractors is discussed; Philco-Ford's development of a destination coding system and techniques for solving optimal routings, General Motors Corporation's development of an installed and operating engineering model, Serendipity's determination of driver-information requirements for ERGS, and Kollsman Instrument Corporation's development of an automobile head-up display for the ERGS routing symbols. A separate section gives a description of the General Motors system design at the functional and component level.

Future development and system benefits are discussed. Dynamic system requirements over and above the present or static ERGS are envisioned, including both additional hardware and software. Benefits to the highway system and to the highway user are given for the static or preprogrammed system and for the dynamic system. A highway transportation subsystem which could be implemented in the near future, and which retains the driver as an integral part of the system, but is expected to enhance the driver's performance by unburdening his route guidance task and allowing more attention to the primary task of controlling the vehicle, is presented. Furthermore, the addition of central control facilities and communications links to intersections is expected to permit more uniform distribution of traffic over the highway network.

Manuscript received August 7, 1969; revised October 10, 1969. Background information for this paper was developed during in-house research by the Office of Research and Development of the Bureau of Public Roads. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the Bureau of Public Roads.

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I. Introduction

THE ELECTRONIC route-guidance system (ERGS) is the culmination of about three years of in-house and contract research and development by the Bureau of Public Roads, Federal Highway Administration. In its present form, ERGS offers a new concept for guiding the motorist more safely and efficiently than is possible with present maps and signs. In its ultimate development, the system offers great potential for relieving urban congestion and providing ancillary benefits to all highway users.

This paper will briefly describe the highway routing problem, outline the Bureau's five-phase development program, describe the system design details at the component and functional level, and give highlights of future development plans and expected system benefits. Readers interested in more detailed information about the system and its development should consult a recent publication of the Highway Research Board [1]–[5].

II. The Highway Routing Problem

The problem of finding one's way safely and efficiently on today's complex system of highways has reached serious proportions. Testimony to support such a statement can

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be found in one's own driving experience. Lighter evidence which mirrors the problem can be found in the abundance of cartoons on the subject. For example, imagine the stunned look on the face of the "driver-husband" when the "navigator-wife" informs him, "You should have taken a left turn two states back!" But for serious comprehensive testimony on the problem, the reader is referred to the recent U. S. Congressional hearings [6].

In this paper, the highway routing problem is subdivided into two basic categories, "static" and "dynamic." This dichotomy is an oversimplification of the problem but, it provides a convenient framework for discussion.

The static routing problem is exemplified by the difficulties unfamiliar drivers have while traversing the highway network over a "best route" (e.g., minimum-time path) using only conventional maps and signs. The dynamic routing problem is exemplified by the difficulties both familiar and unfamiliar drivers have while seeking best routes through highway networks (mainly urban) wherein traffic and other conditions are varying with time.

The generality of sign messages and the lack of uniformity of maps are the chief reasons for static routing problems. Symptoms of these problems are, for example, driver uncertainty at decision points and excessive travel in the system. Driver uncertainty contributes to turbulent inefficient traffic flow at road junctures, and is a recognized safety hazard.

Dynamic routing problems arise primarily because individual drivers lack knowledge of alternate routes and traffic-control systems do not include comprehensive surveillance capability and responsiveness to varying demand. One of the most prominent symptoms of this class of problems is the congestion and delay on certain routes, while potential alternate routes are operating below capacity.

III. Bureau of Public Roads Five-Phase Development Program

The Bureau of Public Roads, realizing the need for a system to alleviate highway routing problems, launched, in early 1967, a program to research, develop, test, and evaluate the ERGS.

The initial program consisted of five phases:

1) highway coding for route guidance,
2) development of experimental hardware,
3) development of driver informational requirements,
4) refinement and installation of a prototype system on a highway network,
5) testing and evaluation of the route-guidance system.

A description of the development program by phases, and a summary of progress to date will follow.

A. Phase 1: Highway Coding for Route Guidance

This phase was conducted under contract to the Philco-Ford Corporation. A coding system and formating technique was developed for uniquely identifying the intersections in the 48 contiguous states. Basically it consists of a logical technique for naming intersections of a highway network.

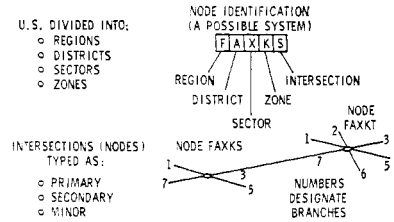

Fig. 1. ERGS intersection coding methodology.

The U. S. highway network, with its estimated 3.7 million miles of roadway and a forecasted 4 million intersections, dictated a systematic technique for proper identification. A dual form of partitioning was utilized; geographical and hierarchical. Geographical partitioning allows a locality to be described by its surroundings; hierarchical partitioning reduces total information loading on the system.

Since the highway network is made up of roads which can be called "links" and intersections which can be called "nodes," a system for assigning a direction to a link going through the node was developed, called the branch designator. The numerals 1 through 8, corresponding to the points of a compass, are assigned to the exiting branches of a node. For example, number 1 would be north, 2 would be northeast, etc., see Fig. 1.

Hierarchical partitioning consists of three levels. The first level, called primary, applies to principle arterial roads, similar to the federal aid primary system, and their intersections. The next level, secondary, applies to roads similar to the federal aid secondary system and their intersections. The third level, minor, designates all other roads and intersections connected to the other two levels.

The geographical partitioning divides the United States into regions, districts, sectors, zones, and nodes, as shown in Table I.

The code adopted to identify uniquely each of the four million nodes uses alphabetic symbols. If each geographical subdivision is assigned a single symbol, a code word of five letters can uniquely identify any network intersection. An example of a coded intersection is $AGFAB$, which designates (reading right to left) intersection B, in zone A, sector F, district G, region A.

To facilitate use of the code by the general driving public, a two-letter state prefix is substituted for the single-region designator, The result is a six-letter state-prefixed "node name." The example cited previously would convert to a node name of WA–G–FAB, which is an intersection in the city of Tacoma, Wash.

Psychological research has indicated that people more easily remember grouped symbols, especially if they are pronounceable. Hence the state prefix is separated from the district designator, and the district designator from the three-letter suffix which designates the primary, secondary, or minor node. To help form pronounceable syllabic

TABLE I
ERGS CODING METHODOLOGY
GEOGRAPHICAL AND HIERARCHICAL PARTITIONING

Partitioning	Region	District	Sector or Primary Node	Zone or Secondary Node	Minor Node
U. S. A.	20	500	10^4	2×10^5	4×10^6
Region		25	400	10^4	2×10^5
District			20	400	8×10^3
Sector				20	400
Zone					20

code suffixes, the consonants H, J, Q, X, and Z are not used for the last three alphabetic designators.

Also developed under this phase was an algorithm for the solution of best routes through a highway network. A FORTRAN IV program for the solution of best routes was written and compiled on Philco model 212 computers. The program determines the minimum path and the exit branch which connects each pair of nodes in a matrix representation of a roadway network.

B. Phase 2: Development of Experimental Hardware

This phase of the program has been performed under contract to General Motors Corporation. Utilizing the coding methodology, and best route solutions developed in phase 1, a laboratory hardware model was developed which demonstrated the feasibility of employing communications and digital logic circuitry, to perform all the functions of a conceptually new and vastly superior route-guidance system. This early laboratory model was designated ERGS I. It consisted of roadside circuits mounted in a typical traffic-control equipment enclosure, and vehicular circuits mounted on a small laboratory cart. Also trigger and communications antennas were mounted on the lab cart and to wooden frames, placed on the floor to simulate the roadway–vehicle communication link.

Following the successful demonstration of ERGS I, work was begun on an environmentally hardened and refined version of the hardware for field testing. This version of the system, known as ERGS II, was installed at an intersection in the Washington, D. C., area. Vehicular components were installed in a 1968 sedan. The ERGS II system has undergone extensive testing and evaluation, and has performed reliably over a wide range of environmental conditions.

As a part of this phase of the program, research was also directed toward the development of a head-up display for the route guidance symbols. Kollsman Instrument Corporation was contracted to develop such a display which projects onto the windshield any of 16 guidance instructions as shown in Fig. 2. The image source is a symbol wheel which is positioned by a motor. A 150-candle-power incandescent lamp provides illumination. The optical system collimates the rays so that when they are reflected from the windshield toward the driver, he sees the amber image as if it were suspended in space somewhere beyond the vehicle hood. Consequently the driver does not have to shift his line of vision or refocus

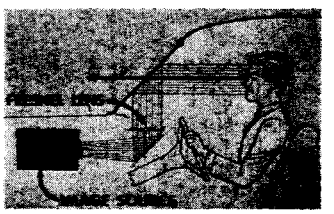

Fig. 2. Kollsman head-up display.

his eyes to see the ERGS instruction, which is visible against all but the very brightest backgrounds. This display is an adaptation of systems now in use in both military and commercial aircraft.

The head-up display has been installed in the same vehicle which contains the ERGS II equipment. The dashboard was modified to accommodate the display. Some limitations in this type of display have been observed, such as lack of adaptability to all windshields, double images, and lack of space in the vehicle instrument panel area. Further development of the head-up display would be a prerequisite to its adoption into the route-guidance system design.

C. Phase 3: Development of Driver Information Requirements

This phase of the project, which ran concurrently with the hardware development, was required to determine driver information requirements at highway decision points. Serendipity, Inc., and Alan M. Voorhees and Associates, Inc., conducted a study based on an empirical analysis of the guidance information which a driver requires and where he requires it, in order to safely negotiate a decision point. Knowledge of these factors is essential to the design of the driver display and the deployment of roadside hardware.

In determining the information the driver requires, the intersection or decision point was analyzed from the driver's viewpoint. This methodology described the actual trace a vehicle makes in negotiating the intersection. The trace can be described by: 1) approach paths, 2) correct lanes, 3) choicepoint (a point at which a driver can choose between two or more exit paths), and 4) close choice point (a point which occurs after the initial intersection but which requires guidance information at a point prior to the intial intersection).

During this phase, a user acceptance study was performed by use of a film questionnaire. The film, "Guiding Tomorrow's Motorist," was shown at the History and

Technology Museum of the Smithsonian Institution. Approximately 1500 people viewed the film at which data was collected using a questionnnaire. Ninety-four percent of the respondents considered the ERGS system desirable. Eighty-four percent preferred ERGS symbols over conventional signing. Forty-three percent said they would buy this type of system. Thirty-nine percent were undecided and eighteen percent said they would not buy the system. Other questions asked in the study concerned the need for particular symbols, deployment criteria, estimated costs, and other questions designed to guage user acceptance.

Based on the information requirements analysis of intersections and the user acceptance study, an ERGS display concept was recommended. The display, designed for the perceptual characteristics of an aged driver, provides all of the information necessary to negotiate intersections with minimum requirements for interpretation and memory.

D. Phase 4: Refinement and Installation of a Prototype System on a Highway Network

The plans for this phase, to begin in the latter part of 1969, include the manufacture, installation, and checkout of a static route-guidance system on a highway network in Washington, D. C., with extensions into suburban Maryland and Virginia. The system will consist of hardware for 100 roadside intersection units and for 50 vehicles.

This phase will be undertaken by the Bureau of Public Roads as a cooperative effort by the Bureau's Office of Traffic Operations and Office of Research and Development and the Highway Departments of the District of Columbia, Maryland, and Virginia.

The hardware to be installed will be based on the ERGS II design, but will incorporate a number of additional features. One of the chief requirements for the new system, ERGS III, will be the necessary circuitry to provide for system surveillance and remote updating of roadside decoder memories. This feature will permit operation of the network of 100 intersections as a system, and is a prerequisite for a dynamic system, as will become apparent later in this paper.

Another potential refinement in the system is simplification of the communication link to combine trigger and information functions, and thus to reduce installation and maintenance problems. Reductions in component size for both roadside and vehicular equipment have also been specified as desirable in ERGS III.

E. Phase 5: Testing and Evaluation of the Route Guidance System

About one year following the installation of ERGS III equipment, testing and evaluation of system effectiveness will begin. Comprehensive testing is being planned to evaluate the effectiveness of the system from the highway authorities' point of view and from the individual user's vantage point. Typical system tests would involve measures of travel time and determination of improvements in traffic-flow characteristics at intersections and interchanges. Typical driver tests would involve measures of stress and vehicle-control stability.

Since one of the major purposes of the testing and evaluation program will be to determine the cost effectiveness of the system, every effort will be made to keep accurate cost records of all aspects of the ERGS III system. Typical cost categories are hardware, installation, operation, and maintenance. Also included are programming and other support efforts from activities such as traffic control which must interface with ERGS operations.

F. Other Program Studies

Since the development of the original five-phase program, a number of other tests and studies have been incorporated. For example, research is currently underway to determine the optimum information lead distance (ILD) for giving the driver the ERGS routing symbols on an approach to a highway decision point.

ILD is being determined by two types of experiments. The first involves a test vehicle containing an ERGS display and instrumentation for recording driver test-subject responses. Test runs will be conducted under actual operating conditions at many of the intersections to be equipped with ERGS III hardware. A second series of experiments is being conducted in a driving simulator which employs a terrain model of about 20 intersections, a gantry driven TV probe, and TV projection into the simulator's vehicle cab. With the simulator, it will be possible to make many more data runs under better controlled conditions than would be possible using only field testing.

Other studies planned include detailed cost analyses of the electronic components employed in the ERGS system. Costs for various quantities and projections of electronic technology will be developed to serve as inputs to various economic feasibility forecasts.

The ultimate objective of the program is to determine the feasibility of the wide-scale implementation of the system in the U. S. highway network. Such implementation would take into account development of related systems for aiding the driver and the implications of the system for urban traffic control and urban transportation planning.

IV. ERGS System Design Details

A. The System in Brief

1) *System Components*: The ERGS system design requires hardware components in participating vehicles and at instrumented intersections. The vehicular components consist of:

a console containing the destination encoder and control logic, communication and display circuitry,
visual display with audio-alert signal,
trigger and communication antennas.

The roadside components at each intersection consist of:

an enclosure containing the destination decoder, con-

Fig. 3. Code letters designating the destination address of the driver.

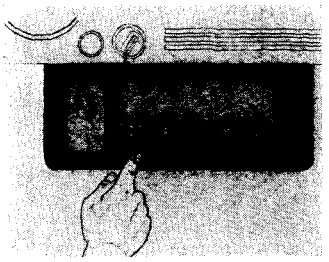

Fig. 4. Driver enters destination code.

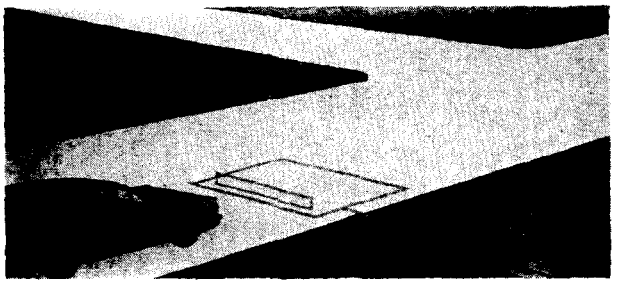

Fig. 5. Car approaches loop.

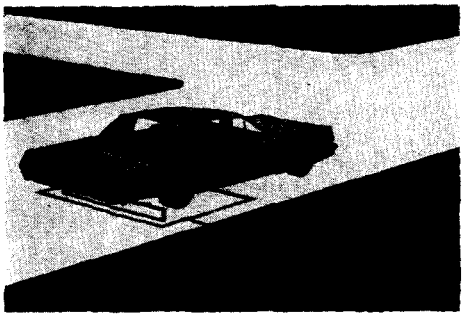

Fig. 6. Loop triggers car transmitter.

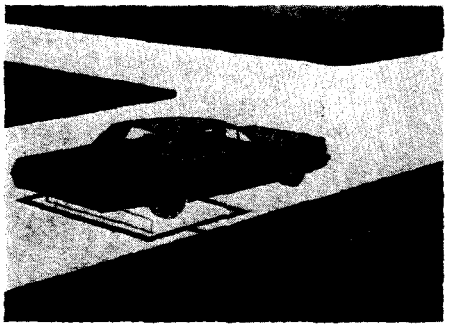

Fig 7. Car transmits destination to roadside unit.

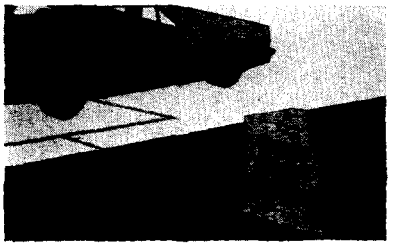

Fig. 8. Roadside unit decodes destination and determines correct routing instruction.

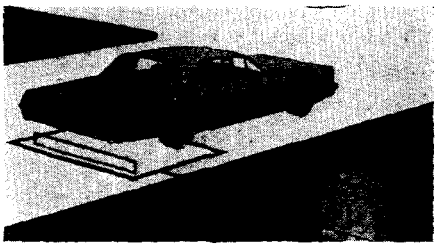

Fig. 9. Roadside unit transmits routing to car.

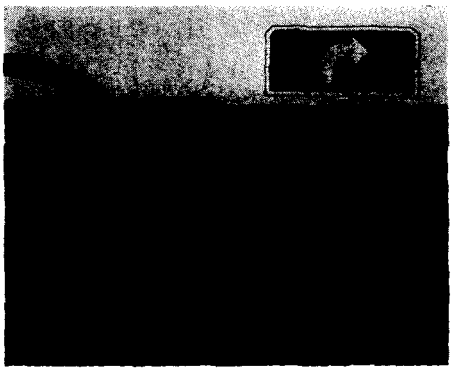

Fig. 10. Routing symbol is displayed to driver.

trol logic, and one communication/buffer storage unit for each approach lane,

trigger and communication antennas buried in each approach lane.

2) *How the System Works*: When the driver starts on a trip, he looks up the intersection nearest his destination in a directory (Fig. 3). Then he enters the corresponding six-letter code word for his destination by setting small thumbwheels on the vehicle console (Fig. 4). As he approaches an instrumented intersection (Fig. 5), the trigger loop antenna in the pavement activates the ERGS equipment in the vehicle (Fig. 6). His vehicle's ERGS unit transmits the destination code to the roadside equipment via the communication loop (Fig. 7). The roadside equipment processes the code (Fig. 8), and communicates an appropriate routing instruction back to the vehicle (Fig. 9). The received instruction (turn right, turn left, etc.) is displayed visually (Fig. 10), at the same time the audio alert sounds. A similar two-way exchange of information occurs at each instrumented intersection on the trip.

The system is destination oriented. If a driver failed to follow or elected to ignore a routing instruction, the

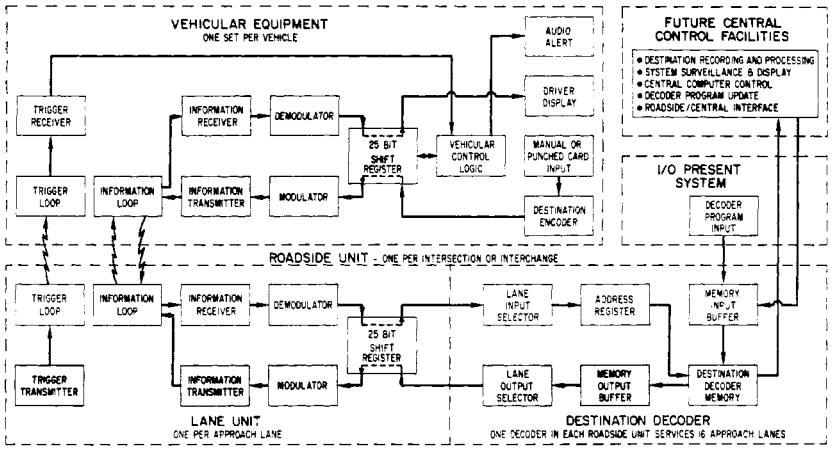

Fig. 11. ERGS functional diagram.

next instrumented intersection would route him to his destination from that point.

B. Vehicular Components

1) *Destination Encoder*: The destination encoder receives the input from the driver. It includes five alphabet-coded switch assemblies, each with a thumbwheel which the driver manually positions to enter the code word for his destination. Each thumbwheel positions a perforated coding belt. Five contact fingers electrically sense the coding holes punched in the belt, to transmit 25 binary bits to the roadside equipment. Thus each switch assembly electromechanically converts one of the alphabetic characters into a 5-bit binary-code equivalent. Alternatively, the driver may insert a punched card to enter the destination code. The coding holes in the card are sensed by a separate set of contacts. The card overrides the setting of the coding belts.

2) *Control Logic:* The digital circuits in the vehicle equipment (Fig. 11) perform the following functions:

convert the five-letter destination into 25-bit binary code,
process the trigger signal when the antenna intercepts a roadway trigger field,
modulate the transmitter with the 25-bit binary destination code,
demodulate and store the routing instruction display code received from the roadside unit.

3) *Driver Display*: The display provides the ERGS output, a routing instruction to the driver. The dash-mounted General Motors display has a 16-element backlighted panel (Fig. 12). Individual elements of the panel, or combinations of them, light up to display routing instructions to the driver. Simple instructions such as right turn, straight, left turn, etc., are presented to the driver by simple graphical symbols grouped at the left. For more complicated situations, for example, traffic circles, the verbal portion of the display may be used; 1st right, 2nd right, 3rd right. When it is necessary to give the driver

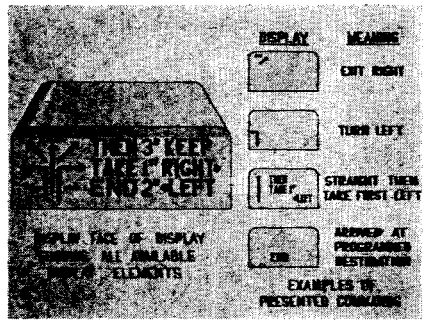

Fig. 12. General Motors GM II display.

more than one instruction, a combination graphical symbol and verbal instructions may appear. (The unit never displays all elements at once).

C. Communication Link

1) *Methodology*: The principal factors governing the design of the ERGS communication link were to: 1) provide specific information to each vehicle at specified points in advance of each significant intersection; 2) keep demands on the radio-frequency spectrum to a minimum, and 3) employ a technique which could be implemented with simple low-cost communications components. The resulting design employs a low-frequency, two-way, near-field, digital communication link. A simple one-turn communication loop antenna operating at 170 kHz is installed in each approach lane at an intersection and is connected to the roadside unit via coaxial cable. A smaller trigger antenna loop operating at 230 kHz is installed just inside the upstream edge of the communication loop. A similar but smaller pair of loop antennas is mounted under the rear of the vehicle to complete the radio link between roadway and vehicle. The sequence of sending the destination code to the roadside unit and receiving the routing instruction is initiated, when the vehicle passes over the roadway trigger loop and is completed before the vehicle leaves the communication loop. The sequence takes from 21.0 to 24.3 ms.

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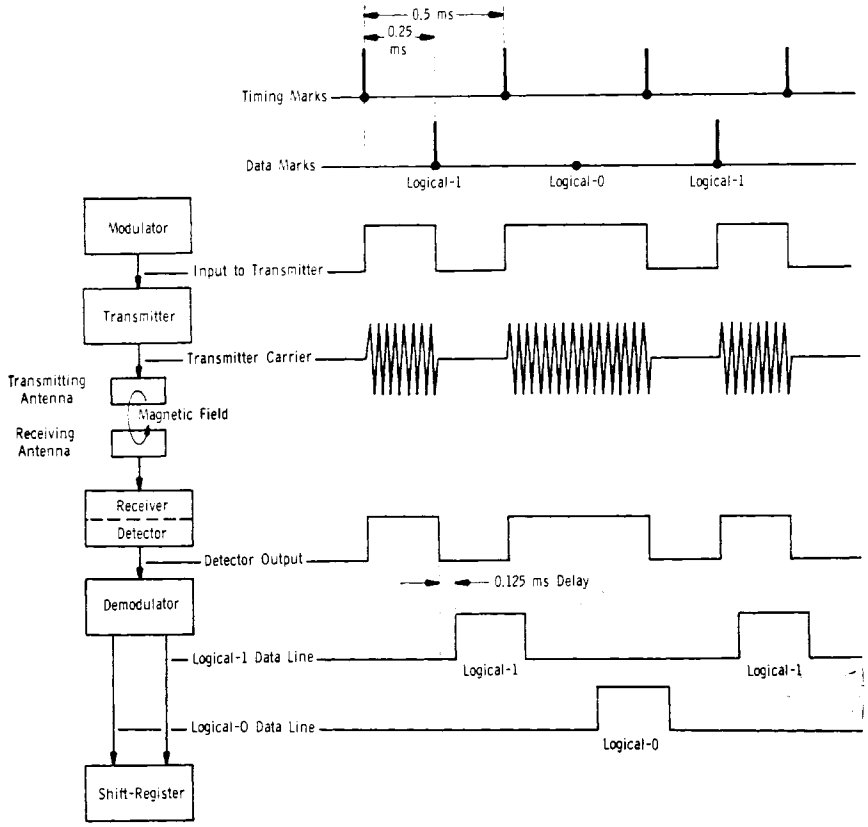

Fig. 13. Modulation technique.

TABLE II
ANTENNA DIMENSIONS

	Roadway	Vehicle
Communication loop	5 ft by 8 ft	6 in by 35 in
Trigger loop	1 in by 7 ft	1 in by 27 in

2) *Antennas*: Road and vehicle antenna pairs are electrically and mechanically similar. Communication loops are larger and mounted in a horizontal orientation. Trigger loops are smaller and are mounted in a vertical orientation. Typical dimensions for a 12-foot lane and a standard-sized sedan are shown in Table II. Roadway antenna installations in adjacent lanes are longitudinally staggered 7 feet to avoid mutual interference.

3) *Transmitters and Receivers*: The basic roadside equipment contains separate lane units for each approach lane at the intersection. Each lane unit contains a trigger transmitter, a communications transmitter, and a communications receiver. Vehicular counterparts include a trigger receiver, a communications transmitter, and a communications receiver. Identical communication transmitters and receivers are used in the vehicle and in the roadside lane equipment. Each transmitter delivers approximately two watts of power at 170 kHz to its antenna feedline. Road receiver sensitivity is nominally set at 70 mV, referred to the antenna terminals, to reach detector threshold level. Vehicular receiver sensitivity is nominally set at 140 mV.

The trigger transmitter in the roadside and the trigger receiver in the vehicle are nearly identical to the communication transmitters and receivers except that they operate at 230 kHz, employ an unmodulated continuously energized carrier, and require essentially zero bandwidth.

4) *Modulation Technique*: The ERGS communication link is asynchronous; thus it is necessary to include timing marks along with the data, to establish the framing of the incoming signal, so that the demodulator can sample the received waveform at the proper times. The goal in the hardware design is a low-cost system in which any vehicular unit will synchronize with any roadside unit, and can operate for months or even years without regular maintenance or calibration. Therefore, the modulation system transmits a timing mark along with every information bit (data mark), and can tolerate wide variations between individual pieces of equipment.

Coded information is transmitted by keying the 170 kHz transmitter carrier on and off (Fig. 13). The transition of the carrier from off-to-on or on-to-off is recognized by the demodulator, and produces an output data signal. Data transmission rate is 2000 bit/s. A reference timing mark precedes each data bit. The reference timing mark always causes the transmitter carrier to change its state, off-to-on or on-to-off. The data bit, transmitted midway between reference marks, changes the carrier state if the data bit is logical 1, but does not change carrier state if the bit is logical 0. In this modulation arrangement, the state of the transmitter carrier at the end of a transmis-

sion depends upon the data content. Logic circuitry, therefore, resets the transmitter carrier to off at the end of each transmission.

The signals on the data lines (output of the demodulator) are delayed by 0.125 ms. The delay occurs because the output signal of the receiver–detector circuit is integrated before it is accepted as a valid signal. Unless the output of the detector stays "true" for a minimum of 0.125 ms, the signal is rejected. This procedure effectively prevents impulse noise sources such as ignition and lightning from interfering with the proper operation of the communication link.

D. Roadside Components

1) *Lane Units*: Since the equipment at each intersection must provide simultaneous communication between the roadside and all vehicles approaching the intersection, separate lane units are provided for each approach lane. Each lane unit contains the communication and logic components to trigger the vehicle's destination transmission, receive and store the 25-bit destination code until it is processed by the decoder, and store and transmit to the vehicle the 16-bit driver instruction display code.

2) *Control Logic*: The roadside control logic consists of digital circuitry which sequentially tests the lane units for the presence of a destination code at a 1-MHz rate. When a destination code is detected, testing stops and decoding starts. Upon completion of decoding the driver, instruction is shifted into the lane unit, and the sequential testing resumes.

3) *Destination Decoder Logic*: The decoding process starts when the roadside control logic detects a destination code in one of the lane units. The five-level alpha code (25 bits) is decoded, one character at a time, beginning with the region level and progressing through district, sector, zone, and intersection. A program based on presolved best routes to any destination is stored in the 1024, 8-bit word memory.

Decoding proceeds until an exit number corresponding to the correct intersection exit branch for the vehicle's destination can be specified. The proper instruction to be returned to the vehicle depends not only on the exit-number designator but also on the inbound lane position of the vehicle. Therefore, the appropriate driver-instruction code is selected from the memory, as determined both by which lane unit is being serviced, and by the decoded exit-number designator, At this point the instruction may be modified to comply with special local conditions (for example, if a time-dependent turn prohibition is in effect). Thus a preselected alternate instruction can be sent to the vehicle if the desired maneuver cannot be legally executed. Finally, the 16-bit display code located in the instruction table is shifted back to the lane unit for return to the vehicle.

The decoding process requires 0.16 to 0.24 ms per vehicle, depending on how many characters of the destination code must be examined to obtain an exit-number designator. In the theoretically worst case, in which vehicles simultaneously enter 16 different loops, the 16th vehicle

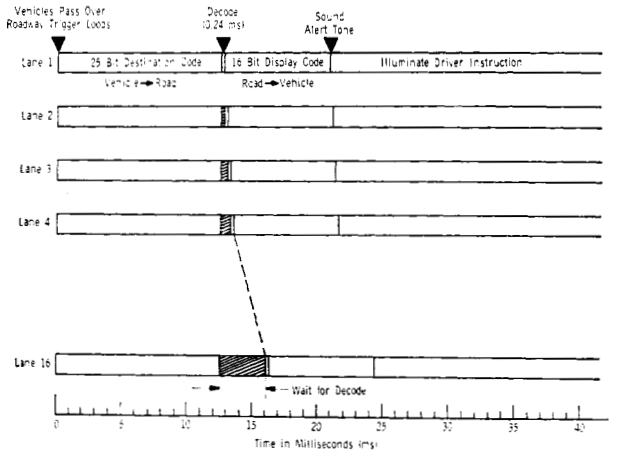

Fig. 14. System timing diagram.

(the last to have its destination code processed) receives its routing maneuver instruction after a lapse of 24.3 ms—2.7 feet of vehicle travel at 75 mi/h. Fig. 14 shows the timing of the steps in the entire process.

E. System Software

Along with the ERGS hardware, techniques and procedures for generating programs for the roadside decoder have been developed. To program a roadside decoder for a specific intersection, the programmer must first have at hand a solution for the best routes from that intersection to all nearby intersections and to groups of more remote intersections. Best route solutions can be obtained by assigning numerical values to the links of the network and exercising minimum path algorithms. Numerical values can represent minimum travel time, distance, or other link characteristics. Next the programmer must have detailed information concerning intersection geometry, traffic regulations, and the location of ERGS loops.

With the above information at hand the programmer then develops three types of tables for the decoder memory. These are the destination, loop, and instruction tables. Work sheets and procedures for handling this information have been developed which employ simple alphanumeric language. A small, 6000, 10-bit word computer utilized as a compiler converts the alphanumeric information into binary tapes which are then fed directly into the roadside destination decoder.

V. Future Development and System Benefits

A. Auxiliary Uses of the Present Route-Guidance System

Although the primary function of the present ERGS system is guidance information for the individual driver, many auxiliary uses may be synthesized. For the most part these auxiliary uses will require additional or modified hardware or software. It should be noted that these uses imply system designs somewhere between the present fully static design and a future dynamic design. Thus they might be thought of as evolutionary developments which could ultimately lead to a dynamic system. The potential auxiliary uses of ERGS are the following:

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data acquisition
routing around preplanned events
truck routing
emergency vehicle routing
flexible transit bus routing
transit bus priority system
programmed scenic and historic tour routing
parking locator system
motorist service locator system.

The auxiliary uses can be divided into two categories; first, those which improve the highway system and second, those which benefit the motorist and the highway system's environment. The former are primarily benefits which accrue to the highway because of data acquisition.

Traffic surveillance and data acquisition are major problems which need to be overcome in today's highway transportation. The ERGS system can make a significant contribution in alleviating these problems. The detection of a vehicle's presence and its destination code permit the identification of important highway parameters such as volume, data, and origin–destination data. This data may be preserved to any degree of accuracy required by the highway engineer. Macroscopic data may be recorded with inexpensive and unsophisticated equipment. Somewhat more sophisticated equipment might be employed to record microscopic data. The cost effectiveness of employing such recording devices would undoubtedly be substantial.

When compared with current techniques, the costs of acquiring the data should decrease, while the amount and precision of the data would increase. These data, macroscopic or microscopic, would be considered historical. On the other hand, real-time data would be very useful for real-time guidance or network control. This dynamic concept will be discussed in more detail subsequently.

Auxiliary uses would also benefit the motorist and the highway-system environment. For example, the motorist could be rerouted around preplanned events such as detours for construction and maintenance, or civic activities such as parades. Reprogramming the ERGS roadside units to account for these events would reduce driver tension caused by these traffic disturbances, increase safety, and improve the overall utilization of the existing road network. This, like the other auxiliary uses, would require some modification to the existing system.

Special truck routing is another example of auxiliary ERGS capability, There are numerous instances today where trucks are not permitted on local streets and through trucks are directed along truck routes. Minor modification to the existing system could provide the special truck-routing function. An additional device would be required to identify the vehicle as being a truck. This use would also require modification of the software logic.

Similarly, emergency vehicles, like ambulances and fire trucks, could easily be routed to their destination via the shortest path, and possibly in such a way that traffic signals would automatically change to all red to permit emergency vehicle passage. This use would also require a vehicle class encoder and modified software.

During the past few years there has been much talk about flexible transit bus routes, and more recently about providing the right-of-way to buses at intersections. Both of these could be accomplished with very minor modifications to ERGS. The hardware and the software changes would be similar to those required for emergency vehicles. Both of these systems would necessitate a communication link with nearby traffic-signal controllers.

Programmed scenic and historic tours are possible by sequentially encoding the points of interest in the order the driver wishes to visit them. Use of the system in this manner would require no modification.

Parking is another great problem today. ERGS could direct the motorist to the nearest lot with available parking, or perhaps to the least expensive one in the vicinity. Since much of our traffic in the central business district is invariably circling around the block looking for a parking space, the benefits of reducing such wasteful driving would be enormous.

The last auxiliary use to be mentioned is the routing of the motorist to services such as gas, food, and lodging. Imagine an encoder which the driver can use to select the service that he needs. Perhaps a credit card might be used which would even direct him to the specific service he prefers. Much driver frustration might be eliminated with such a system.

B. Dynamic Route Guidance

Dynamic route guidance is much more than guidance of the individual driver to his destination. As stated earlier, the present static system uses historical data to route the driver by the best route. A dynamic system would employ real-time data in conjunction with a central computer, to continually update the guidance information. Real-time data is most important when the guidance criteria is minimum travel time. Obviously many constraints affect travel time through a network. Among these are traffic congestion, accidents, civic events, and ordinary detours. The optimization of a trip requires not only instantaneous data about such occurrences, but also some predictive mechanism to insure that overall network operation is actually optimized. For example, it is possible that a static system could route enough traffic via historical best path to create congestion and thus cancel any benefit the system would otherwise have produced. A dynamic route-guidance system would circumvent such a problem.

A dynamic system with its central facilities would provide many functions in addition to guidance and active network control. These functions are summarized in the following list:

computations
surveillance
monitoring
data reduction
data storage
data retrieval
dispatch
communication terminal
control.

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Surveillance might include visual displays of how the network system is operating. System hardware could be monitored to detect malfunctions and maintenance personnel dispatched with minimum delay. Similar operations might include the dispatch of emergency vehicles. The central facility might receive a call for help with the location of the request or its code name, and immediately relay the address code to the appropriate emergency dispatch center. The benefits of this type activity are obviously less time to dispatch a vehicle, and less time to reach the scene of the emergency.

The hardware requirements for a dynamic system are primarily computer oriented. A central control would be needed to house a large computer and its associated facilities. The computer would be linked to the ERGS roadside hardware via telephone or other communication channels. Some traffic data may be acquired from other than ERGS loops. Events such as accidents might be communicated to central control via police radio, airborne observers, or citizen calls. The central facility would thus provide methods for rapidly inserting these data into the computer. Finally, data on preplanned events, such as road construction and parades, would be input to the computer to determine the best strategies for routing individual vehicles. Routings would be coordinated with traffic signals and other variable traffic-control devices. The static ERGS hardware would require only minor modifications to operate in the dynamic sense, since it has been developed with the dynamic system as its objective.

Development of software for the dynamic system, on the other hand, may present major problems. Research is only now being started to determine the software needs. Efficient algorithms, which can handle large networks and the great amount of data thus implied, will have to be developed. Strategies must be developed to route only the correct proportion of drivers via parallel routes. Research will be needed to determine driver utilization and the acceptance of the dynamic system.

Also envisioned is a methodology for acquiring origin–destination data from roadside units and forecasting real-time demand on network links. Demand would be compared to capacity, and routing strategies would operate to maintain traffic flow below the link breakdown volume.

To most readers, the objectives of the dynamic system are probably self-evident, and the constraints to obtaining them appear severe. Obviously much research is still required to develop the software that would operate such a sophisticated information and control system.

C. System Benefits

The possible benefits of a vastly improved route guidance system cannot be over-emphasized. They are summarized in the following list:

reduced trip time
reduced driver tension
reduced congestion
more effective utilization of existing roads
increased safety
reduced air pollution
reduced vehicular operating costs
improved roadside aesthetics
savings in new road construction costs
reduced signing requirements.

A primary benefit is the reduction in overall trip time, not only for the unfamiliar driver, but also for daily work trips over known routes. Preliminary evidence suggests that an ERGS system will reduce heart rate. Lower heart rate means less anxiety and fatigue on trips with attendant safety benefits.

A dynamic ERGS system would reduce congestion and thus provide more effective utilization of existing roads. This in turn implies improved safety conditions, reduced vehicle operating costs, and less air pollution per vehicle mile of travel. Effective utilization of existing roads would also lessen the need for additional lanes and produce a savings in new road construction costs. Finally, in-vehicle personalized signing would reduce roadside signing requirements. Signs are often aesthetically unpleasant and are a recognized collision hazard.

While quantification of the above benefits must await further testing and evaluation it does not appear premature to suggest that the ERGS system, which could be implemented in the near future, offers substantial improvement in the quality of highway transportation.

ERGS retains the driver as an integral part of the system, but will enhance the driver's performance by unburdening his route-guidance task and allowing more attention to his primary task of controlling the vehicle. Looking further into the future, the system should be viewed as a stepping stone toward an integrated highway information and control system. Ultimately, the logic and communication elements of such a system could evolve into a fully automatic highway system.

Acknowledgment

The authors wish to acknowledge the contributions to this paper which came from the final reports of the Bureau of Public Roads various contractors. Much of the material on ERGS system design details is taken, with only minor modification, from the reports of General Motors Corporation's Research Laboratories and Delco Radio Division.

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