Electronic Control of Motor Vehicles on the Highway

Part I. Development

V. K. Zworykin and L. E. Flory,
RCA Laboratories, Princeton, N. J.

Modern engineering in both roads and automobiles, and the resulting higher traffic speeds, have pointed to the need for consideration of methods to relieve the driver of some of the mechanical tasks of driving. From a purely technical standpoint it is entirely feasible to think in terms of completely automatic control of vehicles on limited-access highways.

It is obviously not feasible, however, to consider any immediate or sudden change to a system of automatic control. Any such system would have to be introduced on a step-by-step basis and at all stages would have to be compatible with existing traffic.

One of the primary requisites of any vehicle control system is to know the position of every car on the highway. This implies some means of vehicle detection.

The second requirement is to make known the presence of every vehicle to the other vehicles most immediately concerned, usually the vehicle following behind. This implies a means of communication between vehicles or between highway and vehicle.

The third step is the application of automatic controls to a vehicle in response to the information received.

In the proposed system the detection is accomplished by a series of wire loops buried in the roadway. The passage of a car reacts on the loop in such a way that its presence is detected by an electronic circuit alongside the road. Thus every passing vehicle leaves its record in the form of an electrical signal.

Communication with following, and in some cases other, vehicles in an interim system might be by a series of lights along the road which would be lighted following a car and thus, in poor visibility or around a curve, warn a following driver of its presence. This would require no special equipment in the vehicles. In an automatic system the communication would be by means of radiated signals from antennas in the road. These antennas would be excited in response to a signal from the detector. The radiated "tail" thus produced would extend behind the car a distance which might be a function of its speed. This signal would be picked up by a following car carrying receiving equipment. The signal received can be used to operate the accelerator and brakes to prevent the controlled car from approaching too close to the preceding one for safety.

The final basic feature is guidance, which is accomplished by a high-frequency cable in the center of the lane in conjunction with a balanced receiving system coupled to the steering mechanism of the car. By this means the car can be made to follow accurately the path of the buried cable at any speed.

By sufficient refinement of this basic system automatic control of any degree can be built up, limited only by economic consideration and the amount of complexity it is desirable to incorporate.

All of the basic features have been demonstrated by actual operation in a highway in cooperation with the Nebraska Department of Roads. The next logical step is to build up an expanded test facility of perhaps two miles in length in which all of the features, including complete vehicle control, could be tested. Many variable factors exist which can only be determined by actual test on a full-scale installation.

• THE IMPORTANCE of improved safety on the highway need not be stressed. The growing figure of over 100 traffic deaths per day is sufficient evidence in itself that some means of improving the control of motor vehicles is required.

Continual improvement in both highway and automotive engineering is having two effects. First, it is increasing the speed at which traffic moves. On modern highways this is not of itself dangerous. However, it places increased demands on the reaction time of the driver. Second, on limited-access highways and turnpikes the driver, under normal conditions, is reduced essentially to an automaton, with the sole function of providing the small amount of control needed for guidance and maintenance of a fixed speed. As a result the hazards of carelessness and drowsiness increase with the increasing use of turnpikes.

These considerations, together with the additional hazards of poor visibility in fog, smog or darkness, have led to consideration of possible ways in which electronics might relieve the driver of his semi-automatic functions and thus minimize the human factor in the cause of accidents. These studies indicate the technical feasibility of automatic vehicle control and raise the hope that it is the ultimate solution to the traffic accident problem. In addition to the aspect of safety, an automatic control system would increase the efficiency of utilization of the highway.

It is, of course, apparent that a complete system of vehicle control cannot be introduced overnight. Sudden conversion of thousands of miles of roads and tens of millions of vehicles from manual to controlled operation is obviously impossible. A system of vehicle control is practical only if it can be introduced on a gradual or a piecemeal basis. This leads to the further obvious conclusion that any automatic driving system must be compatible with present-day driving conditions; that is, controlled and uncontrolled vehicles must move freely in intermixed fashion with no interference. Furthermore, any modification in highway construction must either leave unchanged or improve the safety of operation of any car using the highway. Finally, any auxiliary equipment in the car must aid its user without adding new hazards for the driver who does not have it. In brief, electronic control must at all stages blend smoothly with existing operating conditions.

In the interest of optimum maintenance, as much of the equipment as possible should be under direct control of the highway personnel. In other words, the work so far has been in the direction of installing as much of the system as practicable in the highway itself. This, it turns out, is completely in accord with the concept of the optimum technical approach to the problem.

REQUIREMENTS OF SYSTEM

What are the requirements for a complete, compatible, automatic control system? The first is the ability of the highway to sense the location of every vehicle on it whether or not it has any special equipment. The second requirement is a means of communication between highway and vehicle to make available to the driver of an equipped car this information, particularly as it relates to the position or motion of the vehicle ahead with respect to his own car. The third requirement is the application of controls to the vehicle in response to signals from the highway.

Vehicle Detection

The first requirement, that of sensing the presence of a vehicle, implies some type of vehicle detector. This is the most basic element of the system and the one which has so far received the largest share of attention.

The detection system consists of a continuous series of electronic circuits buried in and along the highway. These circuits generate an electrical signal in response to the passage of any vehicle. The portion buried in the roadway consists of wire loops of a size comparable to that of a car. Alongside the road an electronic detector associated with each loop or groups of loops responds to the change in inductance of the loop under the influence of a passing car.

The information concerning presence of the car can then be used in various ways to activate other parts of the system. The loops of wire can be quite simply installed in the roadbed during construction and have been installed experimentally in existing roads by a diamond-saw technique.

The detector unit is relatively simple, consisting in its present form of two vacuum tubes and associated circuits. It is now being redesigned to use transistors in order to achieve greater reliability and much reduced power consumption. This unit can be completely buried in roadside boxes and arranged to be readily exchanged if maintenance is required. A simplified schematic diagram of the road installation is shown in Figure 1.

Communication of Information

In a lane of moving traffic every vehicle is most concerned with the vehicle directly ahead of it. Therefore, it is important to communicate information as to the action of a vehicle to the following one. This may be done in a number of ways consistent with the stage of development of the system. The basic element, however, is the generation of a "flying tail" signal which will trail a vehicle and some means in the following car to detect this tail at a safe distance, permitting appropriate action to be taken. In an interim system the "tail" may be in the form of a series of lights which are lighted for a distance following a car. In areas of poor visibility, around curves or over hills, the "tail" of lights would warn a driver of the presence of a car ahead. A series of lights can equally well be lighted for a distance in front of a car, around a curve or over the brow of a hill, to warn drivers ap-

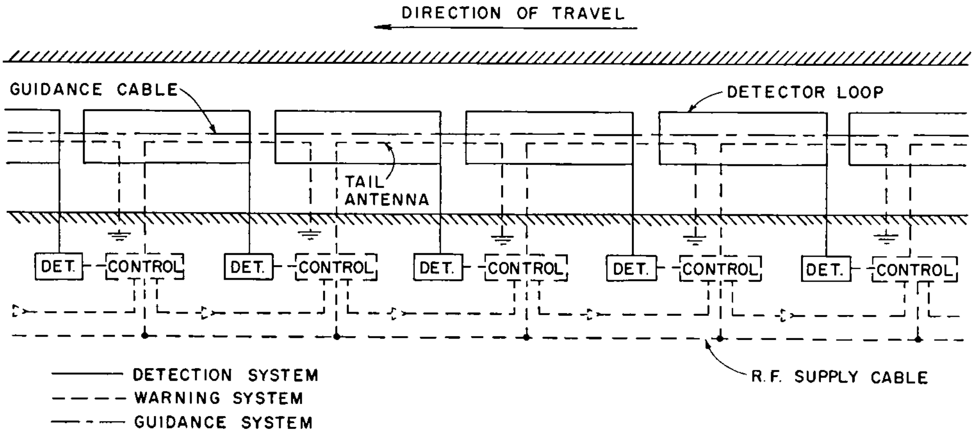


Figure 1. Simplified schematic of road installation. Basic elements of electronic control system include wire loops imbedded in the roadway plus detector units which respond to change in loop inductance under influence of vehicles. Associated with each detector is a control element which activates a radiating system extending back from the loops to provide a "radio tail" warning. The continuous line running through all the loops is the guidance wire, which provides the signal for steering an equipped car.

proaching in the opposite direction. This embodiment would require no equipment in the car and might conceivably be installed in isolated portions of a highway where special hazards or poor visibility exist.

In later phases of the system a radio tail trailing the car would supplement or replace the tail of lights. This radio tail would be detected by a receiver in the following car. Initially, the detected signal would simply light a warning light or sound a buzzer inside the car, indicating a condition requiring action on the part of the driver. In a completely developed system the signal received would act directly on the accelerator and/or the brakes so as to correct the dangerous condition.

The effective length of the tail (in other words, the minimum distance allowed between cars) can be controlled in various ways. It can be made to vary with the speed of the first car whether equipped or not. It can be made to persist for a time after the car has passed. The sensitivity of the receiver in the following car can be made a function of its absolute speed, whereas the rate of change of the received signal is a measure of the speed of the car relative to the one ahead.

In addition to all of these, the length of the tail can be controlled independently from the highway to adjust spacing to conform to traffic and road conditions. In a similar manner, it is possible to introduce signals from control points or gate stations to control the maximum speed. By making use of all these possibilities, vehicle spacing can be automatically controlled to maintain the conditions of maximum safety and, at the same time, maximum utilization of the highway facilities.

Vehicle Guidance

The final basic element in the control system is a means of guidance. This can be realized by a buried cable running down the center of the lane and carrying a high-frequency current. A pickup coil on each side of the car receives a signal from the cable.

The two signals are arranged to oppose each other. When the car is centered over the cable the signals balance and the car moves straight ahead. When it becomes displaced the signal from one pickup coil will increase while that from the other will decrease and an unbalanced condition will exist. The unbalance signal will operate the power steering mechanism of the car to restore it to the center of the lane.

In a dynamic situation with properly stabilized servo controls the car will proceed down the cable with no wavering. With this means of control it is impossible for a vehicle to get out of its proper lane without deliberate action of the driver.

FIELD INSTALLATION

It is possible to design a complete system of highway controls based on the control elements described. All of the electronic means exist for accomplishing any degree of control which can be economically maintained.

The basic features of the control system were recently tested and demonstrated with the cooperation of L. N. Ress, State Engineer, Nebraska Department of Roads. Mr. Ress' department installed a 300-ft section of controlled highway in a newly constructed intersection in Lincoln, Neb. Part of the test installation is shown in Figure 2.

The physical installation of this test section is described in more detail in another paper. The demonstration covered the operation of the vehicle detectors with buried loops, the tail warning system employing both lights and radio signals, and the guidance system.

FUTURE PROSPECTS

Although complete automatic control is obviously something for the future, these tests indicate that some elements might be introduced to advantage at any time with a view toward an eventual growth into a complete system. For example, use of a series of vehicle de-

Figure 2. Experimental installation of vehicle control system, Lincoln, Neb. Detectors are in elevated boxes along the right-hand side of the roadway. Note the two lights at right center lighted in response to passage of the two cars. Note also light on top of rear car lighted in response to "radio tail" of preceding car.

tectors permits monitoring of the passage of cars over any desired section. The information thus obtained could be used to operate traffic lights in a truly proportional manner, making for maximum utilization of highways at intersections while maintaining complete control for maximum safety. Where vision is obscured by hills, curves, or fog, cars may be advised of the presence of other vehicles by means of systems of lights, as previously described. Figure 3 shows, by way of example, how a warning signal in the form of lights can be pushed ahead of an oncoming car. Similar warning lights trailing a car may be useful in foggy areas.

As already indicated, the next step involves installation of complete equipment in the roadways and of simple warning signal indicators in the car. In this stage it is obvious that the warning could be activated not only by another car but also by any fixed obstruction or a traffic control light. Any degree of control could be integrated with normal traffic, each step adding to the safety of all.

The availability of a means of communication with the vehicles adds another potentiality to the system. It permits the transmission of information apart from the warning signals required for the control of the car. Thus, verbal instructions can be addressed to the driver by means of voice modulation on the guidance signal circuit without any addition to the roadway installation. In particular, route numbers, destinations, etc., may be announced as the car approaches an intersection. Warnings with respect to impending weather changes, unfavorable road conditions, and special hazards along the route may serve to contribute to traffic safety. Important news flashes and emergency orders could also properly be transmitted over the available audio channel. Finally, the driver might be informed in this manner of commercial facilities in the area, such as motels, restaurants, and service stations.

The tests made so far have confirmed the original feeling that a large measure of automatic control is technically possible. At the same time, it has become increasingly evident that electronic control is necessary to cope with the problem of increasing traffic accidents.

But a complete system cannot be developed by any one group alone. Cooperation between highway engineers, automobile manufacturers, and the electronic industry will obviously be re-

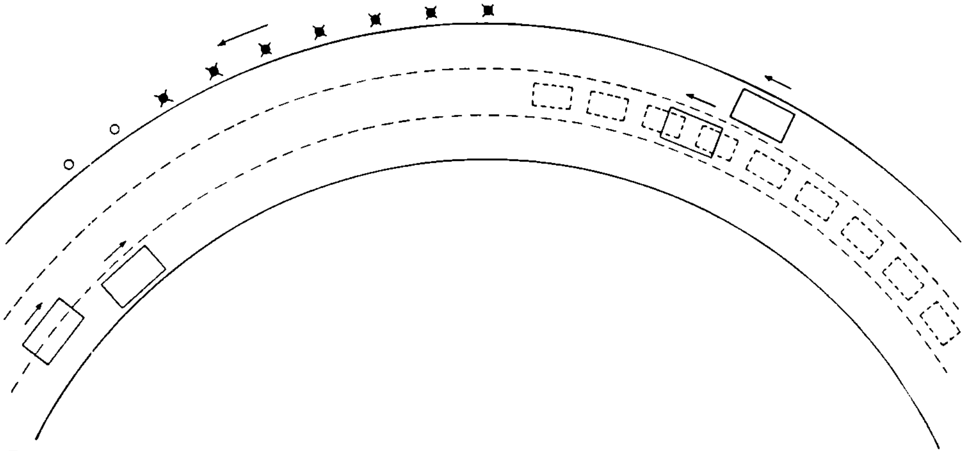


Figure 3. Representative plan of a curve in a three-lane highway shows an application of the RCA electronic highway control system for which no special equipment is required on vehicles. In the situation pictured, the approach of a vehicle in the center lane, moving from right to left, activates a sequential series of warning lights to flash on around the curve ahead of the car, warning vehicles approaching from the opposite direction that the center lane is occupied. Dotted rectangles in center strip at right represent electronic detector units buried in the highway.

quired. The next logical step is construction of an enlarged test facility that will permit testing the various features of the system at full scale and at normal speeds with completely controlled experimental vehicles. Such a facility should be at least 2 miles in length and be constructed with means for performing tests needed for determining the optimum length and shape of the warning tail, optimal dimensions and installation methods for the detector loops, the comparative performance of different types of detectors, and the proper functioning of other components of the complete system.

Part II. Field Test Installation

L. N. Ress, *State Engineer,*
Nebraska Department of Roads

• PARTIAL or complete control of motor vehicles on the highway by means of electronic devices had its beginning somewhere in the nebulous past. The practical application of the basic principles, however, was brought about after many years of study, and in August, 1953, the David Sarnoff Research Center, RCA, revealed a laboratory tested method for automobile driving by means of an electronic automatic pilot system. Since that time, the principles employed in the system have been used to demonstrate the first practical method for developing an accident-free vehicle control system which could be introduced into the existing traffic facilities.

The system as presented is a complete and integrated traffic control system. It has several features which may be of major importance to the highway engineer in the solution of ordinary traffic problems quite aside from the automation driving which the system offers.

One of the more important of these features is found in the method employed for vehicle detection. Under proper conditions, this detection method may provide an economical and efficient answer for "spot" or "continuous" vehicle detection. Because development of these uses would also serve as a check on the feasibility of using these basic principles in the automatic driving system, the Nebraska Department of Roads started a program of field testing several of these basic elements.

The first installation was made in September 1954. It performed satisfactorily under traffic, and consisted of a 4- by 18-ft, two-turn coil of No. 18 TW wire under 1½ in. of bituminous concrete in the center of a 12-ft traffic lane (Fig. 4). It provided a full-scale detector coil operated electronically by the same method proposed for use in the electronic automatic driving system. The operational behavior of the test coil at this location was assumed to be of fairly standard nature.

Encouraged by the results obtained in the first installation, eight test coils were installed to check under field conditions, the performance factors of these coils with different sized wire and different depths below roadway surface. This study showed that although all coils were effective, those placed nearest the roadway surface performed the best and the No. 18 wire coils were more sensitive than those of No. 12 wire. These test results provided additional operational and construction data and were the basis of the first full-scale pilot installation of the vehicle detection experimental project. Although previous tests indicated better results electronically when using coils of No. 18 wire, it seemed rather weak physically, was harder to handle, and exhibited a tendency to float upwards in the concrete during the placing operation. A compromise of No. 14 wire at a depth of 4 in. for all detector coils was finally used.

The test installation at the intersection of US 77 and Nebraska 2 south of Lincoln (Fig. 5) was originally intended as a means for studying the practicabil-

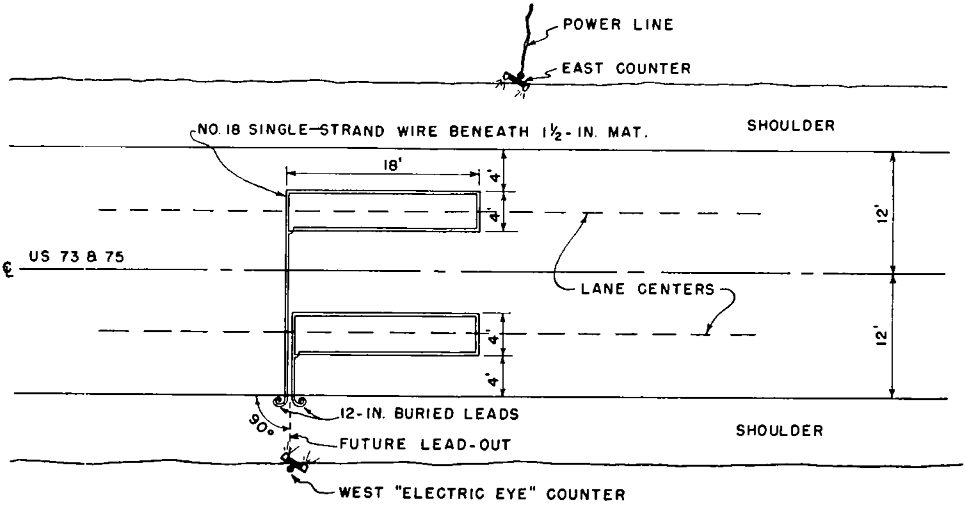


Figure 4. Installation plan of electronic detector road coils, US 73 and 75, Cass County, Nebraska.

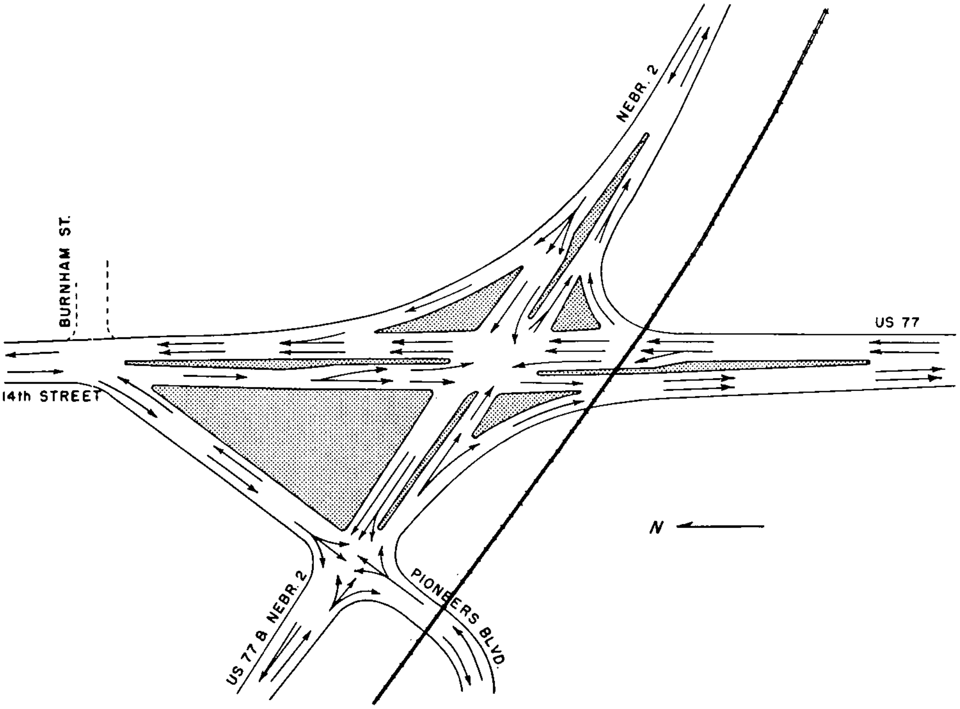


Figure 5. Traffic flow diagram, junction of US 77 and Neb. 2 at 14th Street and Pioneers Blvd., Lancaster County, Nebraska.

ity of utilizing the system for achieving vehicle detection. Once these studies were started, however, it became apparent that the warning and guidance features of the system also should be studied.

At a meeting between RCA officials and the Nebraska Department of Roads in March 1957, it was decided to enlarge the scope of the "electronic study" to include a full-scale working demonstration of all three of the fundamental requirements for complete automatic vehicle operation, with a completion date of November 1, 1957.

This goal was reached by September 10, 1957, and the results were released for national distribution on October 10, 1957. The system consists of three principal parts, as follows:

1. A sequence of detectors installed at intervals slightly greater than car length along the road, designed to indicate the presence of cars passing over them.
2. A radio warning system for following vehicles, controlled by a signal from the detectors.
3. A guidance system which keeps the vehicle centered in its lane.

Several additional uses for these basic principles have been designed and scheduled for further consideration.

The preliminary field studies and complete demonstration are believed to be sufficient to establish the practicability of the proposed electronic automatic driving system.

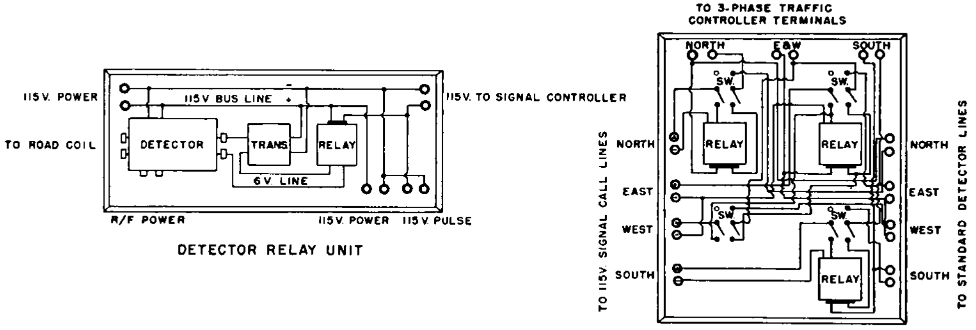
The first long-term study made at the Electronic Vehicle Test Site consisted of a comparison traffic count of west-to-east volume taken on the west leg of the intersection.

The counting unit was operated for a period of 101 days (a total of 2,432 hr) without mechanical difficulty. During this period 41,039 vehicles were counted, with an accuracy compared to an ordinary pneumatic hose-type counter of 97.1 percent despite an improper circuit balance which was causing efficiency to drop to less than 50 percent of intended sensitivity. During this period, temperatures ranged from 9 to more than 40 F and both snow and rain were experienced.

At the conclusion of this volume count study, the circuit unbalance was corrected and a built-in crystal controlled oscillator was added to each of the electronic detector units, the operating frequency being standardized at 300 kc.

Four of the electronic detector units were placed in service and their operation checked from time to time throughout the summer of 1957, while being used both for traffic volume counting and to vehicle-actuate the standard three-phase traffic signal at this intersection. The electronic detector secondary relays and signal call line circuitry used for this system are shown in Figure 6.

A brief check also was made with respect to the proposed method for guiding an automatically-driven vehicle and the transistorized equipment used was found to be satisfactory.



DETECTOR RELAY UNIT

SIGNAL CALL LINE SWITCHBOARD

Figure 6. Electronic secondary relays.

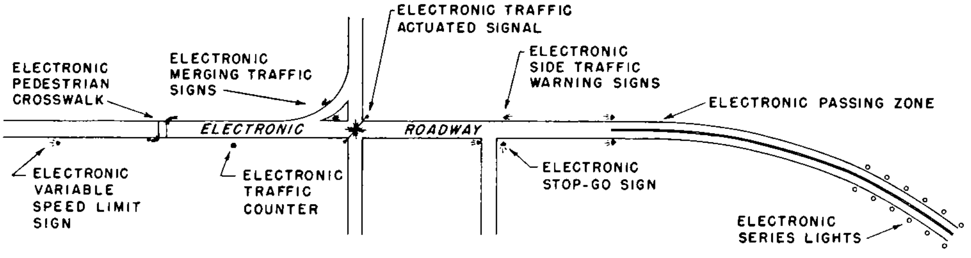


Figure 7. Electronic test roadway layout.

A transistorized oscillator, receiver, and detector switches also were developed to operate the warning signal phase of this study.

A standard amber warning beacon light was mounted above a regular "Merging Traffic" sign in preparation for illustrating the fundamental principles involved in continuous detection, or "lane tracking."

During the course of study of the basic requirements of detection, warning, and guidance for operating an automatic pilot vehicle, a number of possible uses inherent within the electronic system and compatible with the manual operation of vehicles became apparent. Several of these uses are shown in Figure 7.

The electronic variable speed limit sign would constitute merely a system of counting vehicles into and out of a designated length of roadway, the illuminated copy changing to a lower figure whenever a predetermined congestion figure is reached on a multi-stepping relay system. Periodic reset would keep the tabulating balanced and compensate for loss through sidestreet or driveway leaving, whereas ordinary photoelectric control would turn on nighttime speed limits.

The electronic pedestrian crosswalk is shown in detail in Figure 8; details for the "Merging Traffic" signs, the electronic passing zones, and the traffic counter are shown in Figures 9, 10, and 11, respectively.

Most of the aforementioned uses of an automatic driving roadway for manual driver aids are dependent on the current-flow sensing switch referred to in the drawings as an "ampere switch." This

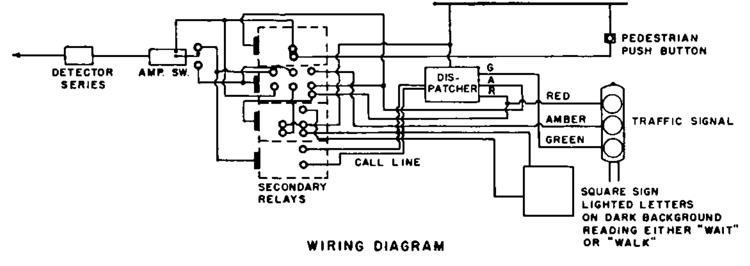


Figure 8. Layout and wiring for electronic pedestrian crosswalk.

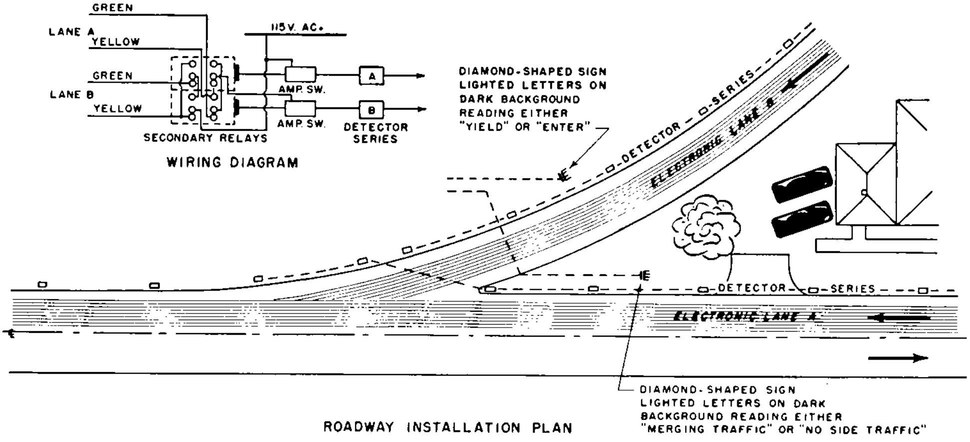


Figure 9. Layout and wiring for electronic merging traffic signs.

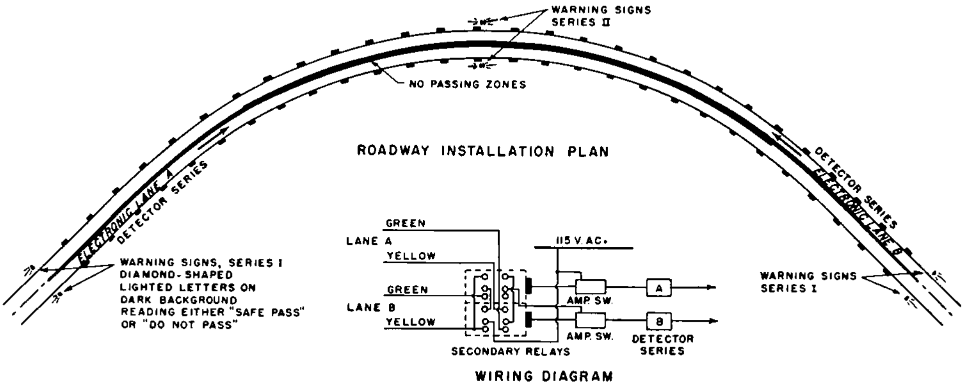
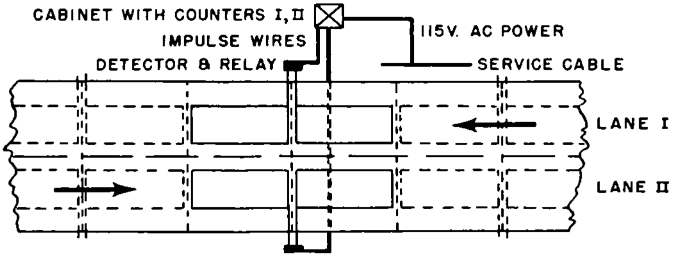


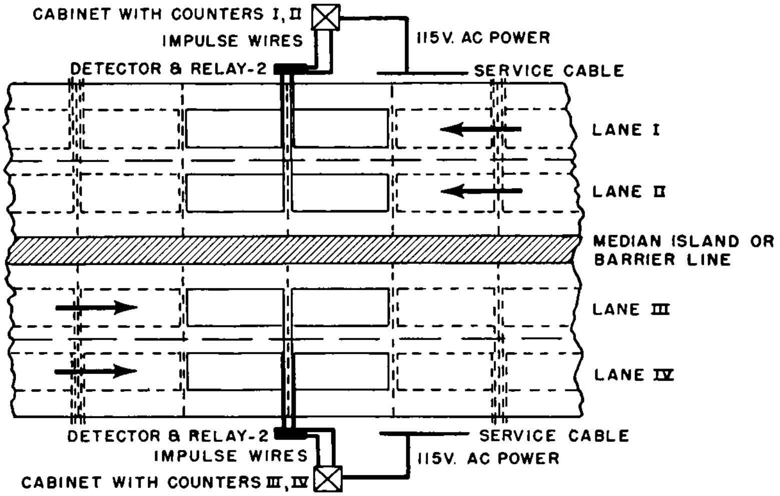
Figure 10. Layout and wiring for electronic passing zones.

device detects the flow of current anywhere it may occur along its associated detector series, and when so energized serves to operate relay contact points, thus switching circuits on or off or to a different line.

The physical installation of necessary wiring and equipment and the operation



DETAIL OF TWO-LANE ROAD



DETAIL OF MULTI-LANE ROAD

Figure 11. Electronic traffic counting layout.

of presently developed transistorized electronic equipment indicate that the development of electronic automatic driving is within the realm of practical usage. The "fail-safe" features developed as basic to the system have been found to be reliable and efficient.

The establishment of a test roadway several miles in length of the nature of that shown in Figure 7 will be accomplished as a development procedure directed toward final establishment of roadway, vehicle, and operational standardization.

DISCUSSION

JOHN J. O'MARA, *Department of Civil Engineering, State University of Iowa.*— Much effective work has been done in applying automatic control to highway traffic; Dr. Zworykin has made the most valuable contribution to this field thus far. In its ultimate development the Zworykin system could provide for positive control of all traffic movement. The radar brake (see paper by Versace *et al.* in this volume) also is significant, because it illustrates that some protection could be supplied by independent means.

The importance of these developments

lies not in their present efficacy or perfection, but rather in their proof of the proposition that considerable improvement can be made in the safety and efficiency of highway transportation through engineering. In transportation engineering operational improvements usually culminate in automatic control.

Many existing parts of the highway transportation system fall into the field of automatic control, whether or not so designated, and could become a part of a fully automatic arrangement. Into this category fall such accepted devices as the expressway, which automatically separates opposing traffic, eliminates cross traffic, and controls access; the traffic-actuated signal with electronic computer and memory; and, in the vehicle itself, power steering, power brakes, automatic transmissions, and speed control units.

One approach to the problem of extending control is to conceive of the highway as being arranged like a railroad with an absolute block system. A railroad-like highway can be designed today, for it would require only separation of lanes, provision of switch lanes, and division into blocks governed by traffic-actuated signals. However, such an arrangement would be cumbersome and inefficient in many ways. If the railroad analogy is to be developed, it should be patterned after more modern arrangements with centralized traffic control (*1*) or the completely automatic system developed by the French National Railways (*2*).

Similar parallels could be drawn with air transportation and with the safest form of transportation, the elevator. A completely automatic landing system for aircraft has been perfected (*3*) and constant control of aircraft in flight is at hand (*4*). The elevator, reaching perfection in the United States, is now completely automatic even to the extent of automatic dispatching for banks of elevators.

Inasmuch as automatic control has proceeded successfully in other areas, there seems to be little reason why a similar success cannot be achieved in highway traffic control provided research is encouraged and furthered.

Development of an automatic system for highways can proceed immediately. Control engineering has progressed to the point that, given the conditions governing a process, differential equations and other mathematical relationships can be established, and satisfactory control apparatus quickly produced by employing established procedures, such as that of the feedback principle (*5*).

General Conditions

The following principles are suggested as fundamental rules for an automatic control system for highway traffic.

1. The vehicle should move efficiently on the highway from entrance to exit.
2. The vehicle must hold properly to an arranged path.
3. The vehicle must not collide with a person, another vehicle, or other object.

Rules 2 and 3 should cover all types of accidents on the highway.

It may be desirable to add a few subsidiary conditions for example, the required changes in the vehicle must not materially impair its mobility when off the controlled highway.

Degree and Type of Control

Control may be automatic or semi-automatic. Under semi-automatic control the system advises the driver of a prudent course of action to be followed to meet a situation. The ordinary traffic signal is an example of semi-automatic control.

An automatic system provides absolute control over a situation. This may include detecting a problem, analyzing it, advising the driver of a prudent course of action, and providing for automatic compliance with its decision or for controlling the vehicle to avoid an accident when the driver or mechanism fails to respond properly. A grade separation structure is an automatic device; the speed governor is another.

The means of control may be static, mechanical, electrical, or electronic. Electronics promises to provide solutions for many functions and, in general, offers the fastest and most reliable apparatus for most operations. Application of electronic apparatus in the highway field is growing swiftly and in a variety of functions: controlling signals, weighing vehicles in motion, measurement and control of speed, measurement and warning of roadway and climatic conditions, etc.

Small electronic computers probably will be required. The use of computers in highway engineering for earthwork and traverse computation is common. It is less well known that computers are being incorporated into traffic control devices. The British Road Research Laboratory years ago began developing a computer to control the flow in signalized intersections based on the theory developed by Wardrop (*6*). Computers for essentially the same type of problem are being developed in the United States, and computers are in use for determining the time for lane reversals on multiple-lane highways and streets (*7*).

There is little need for concern over duplication of effort in developing different devices to perform the same function. In the ultimate application automatic control will need more than one safeguard for any situation, and it would be best if these were based on different but compatible means.

Guidance and Spacing

On the basis of the governing principles outlined, the operations of the control system can be grouped into two categories: guidance and spacing. The Zworykin system provides for guidance by emanations from a buried cable being detected by magnetic pickups on the vehicle. A somewhat similar system, developed and used by the Army for guidance of vehicles in snow fields, employs two buried wires and a much different detection system (*8, 9*). Other guidance media under consideration include colored stripes on the roadway followed by photoelectric cells, radioactive isotopes in the roadway detected by scintillation counters, and a system based on mine detector apparatus.

Non-mechanical guidance systems may not be able to encompass all climatic, roadway, and traffic conditions. A rail, groove, or some similar contrivance may be a necessary addition to the highway. An arrangement of this sort is involved in an elevated transit system which is being considered for commuting service in New York, San Francisco, and Buffalo (*10*). Although this system is designed for driverless electric buses, the buses will be essentially highway vehicles, and many features of the elevated transit system could be applied to highway traffic. These buses will move on rubber-tired wheels operating on a concrete pavement, and the guiding will be done automatically by horizontal guide wheels which will maintain contact with a rail in the center of the lane. An outstanding feature of this design is that a workable switch has been devised which permits access to and from the main track without impeding the normal flow of traffic when the switch is closed.

For longitudinal spacing the Zworykin system provides a "flying tail" signal to warn the following car. A distinct advantage of this arrangement is that it does not involve measurement of distance by apparatus in either vehicle. Devices which measure distance by timing an impulse traveling at the velocity of electro-magnetic propulsion, are handicapped in measuring the relatively short distances required for vehicle spacing. Some progress is being made toward increasing the precision of measuring short distances by these processes (*11*). Other media suggested include sonic, ultrasonic, and infrared waves.

Guidance and spacing are not necessarily separated functions. For example, an effective guidance system probably will maintain proper lateral clearances between vehicles in adjacent lanes and during passing maneuvres.

Other Considerations

In approaching a problem in automatic control it is necessary to decide whether the control is to be independent or cooperative. This decision is presently a concern with engineers designing control systems to avoid aircraft collisions (*12*). Can a mechanism be designed which can control a situation by itself, or must there be cooperative action between the vehicle and the roadway or with other vehicles?

Obviously, independent units are preferable, but there are some operations in which they may not have the required capability. For example, in guidance of motor vehicles it is difficult to imagine a device which would direct the vehicle satisfactorily without reference to a datum in the roadway or adjacent to it. On the other hand, as previously mentioned, an independent mechanism of limited application may be useful as an adjunct to a primary control to increase the safety factor of the system.

Most of the mechanisms and ideas considered so far might be referred to as interior devices; that is, they are contained within the roadway and the vehicle. Exterior apparatus may be necessary or desirable for control, surveillance, or communication. Radio and television present many possible applications. Surveillance of at least selected portions of the highway will be required, and television, as adapted for such work by Malo and others (*13*), offers a good medium for constant or intermittent observation of moving traffic.

Efficiency

Little has been said about the effect of automatic control on the efficiency of highway transportation. The emphasis has been, and rightly so, on the improvement in safety. Yet the possibilities of raising the efficiency are equally amazing. A competent control system will permit much better use of the highway plant; for example, full use of all lanes of a multiple-lane highway during heavy directional flows, and maximum use of the two-lane highway by providing for passing maneuvres whenever safe, rather than depending on the driver's judgment and the sight conditions. The increase in the safe capacity of the highway structure should be considerable.

Related Research

There are many problems related to highway transportation which can and should be studied coincident to the development of a control system. The braking performance of vehicles, to mention one of the many areas, must be determined before control of many operations can be established properly.

In longitudinal spacing it will be necessary to inform the control system of the safe intervals to be maintained under different conditions. This means that the braking characteristics of vehicles under all operating conditions must be determined beforehand (for example, braking from high speed with all its ramifications, including fade, dive, friction, etc.). Braking also involves the guidance problem. If the guidance mechanism controls only the front wheels of the vehicle, uneven braking at the other wheels may create lateral forces resulting in a moment of such magnitude that the control will rupture. One aspect of the skidding problem is the determination of lateral friction between the tire and the pavement, a study currently recommended by L'Association Internationale Permanente des Congrès de la Route (*14*).

Finally, the most important factor to be established for the control system, and for the whole of highway transportation, is the over-all goal. Mumford (*15*) and others have made it quite clear that limits must be established for the motor vehicle transportation system.

Conclusions

In summary it can be said that highway transportation stands on the threshold of safety and efficiency through automatic control. The same ends might be achieved by other means, but automatic control promises a concrete procedure that can succeed. The urgent need is sufficient research personnel and resources to integrate the existing work, establish operating principles for traffic, and complete the development. All segments of highway engineering and transportation must cooperate in this work.

As to the necessity for automatic control, L. R. Hafstad, in a recent address to the Institute of Traffic Engineers, said: "Such systems are sure to come for high-speed expressways." Summarizing the principal reasons for automatic control of industrial processes, the editors of the excellent book "Automatic Control" (*5*) say: "Modern refineries and chemical plants must be placed under automatic control because they are built to carry on processes that are too complex, too fast, and too dangerous for control by human beings except through the mediation of robots." It is only required to add, "and often too monotonous," and the statement perfectly fits motor vehicle operation.

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