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An Anti-Rear-End Collision System

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• IN THE STUDY of electronic aids to highway safety, a particularly alluring subject has been the application of electronics to longitudinal control of individual cars. Two desired gains from this application are a reduction in the number of rear-end collisions and an increase in safe traffic density. In simplified form, this problem is one of controlling a following car of velocity $v_2(t)$ in response to a sensed lead car of velocity $v_1(t)$, so that a finite distance is maintained between the cars. Of course, this assumes that the following car is overtaking the lead car and may not change lanes. If both the lead car's and the following car's velocities, $v_1(t)$ and $v_2(t)$, respectively, were known functions of time, the synthesis of the longitudinal control system would be a rather straightforward problem. Naturally, such is not the case. The velocity $v_1(t)$ may be one of a multitude of forms. The problem is then to obtain the best response of the following car to all forms of $v_1(t)$.

The simplest type of control would be one that would maintain a constant headway. This type of control is basically unstable and cannot be maintained. One may then try to maintain the relative velocity, $v(t) = v_1(t) - v_2(t)$, equal to zero. This is now stable, but provides no consistent headway. Steady-state headway is now a function of the initial headway and initial relative velocity when the following car comes under the influence of the lead car. One may now combine the two previous forms of control, using relative velocity to stabilize the constant headway control systems. This control is characterized by large overshoots in headway in correcting for sudden changes in $v_1(t)$. If any car in a line of cars is disturbed from a constant velocity, the resulting disturbance in headway will build up with distance behind the originally disturbed car until a collision occurs in the line of cars. This is referred to as asymptotic instability.

The shortcomings of straightforward control techniques caused attention to be turned to the human driver. A mathematical relation which describes the motion of his car in response to that of a lead car is termed a driving criterion. A number of these criteria have been proposed as a result of measurements of traffic flow, and are generally of functional form.

$$a_2(t) = f\,[\,v(t),\ h(t),\ v_2(t)\,] \tag{1}$$

The functions in general are continuous functions of time. Here, $a_2(t)$ is acceleration of the driver's car, and $h(t)$ is the time integral of the relative velocity equal to the distance between the cars. A number of these relations have been examined (1), and all of them have been found inadequate to describe what the driver is actually doing. Incidentally, because the criteria variables are those of absolute and relative motions of the cars, the response of the controlled car will be the same whether it is achieved by a human driver or by a fully automatic acceleration control system.

The inadequacy of the continuous criteria functions led to a more detailed examination of existing human driver characteristics obtained from an analog computer simulator in which the driver was following a lead car of constant velocity. This is referred to as the small signal case, because only small perturbations from zero relative velocity and from the desired constant headway are encountered. Test data indicated that a driver changes his acceleration according to a change in sense (from positive to negative or vice versa) of the relative velocity. However, the form of the acceleration (rather constant discrete levels) was independent of the form of the v(t) function

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(continuously varying). This led Barbosa to propose the decision point model of the human driver. This model as developed by Todosiev helps to explain several characteristics of the human driver in the car-following situation. Mainly, though, it suggests that the driver instead of continuously tracking a continuous time variable, actually selects a constant acceleration and holds it until the variable exceeds some arbitrary threshold, at which time he changes to another level of acceleration and holds that, etc.

The development of the automatic longitudinal control technique has paralleled this break from continuous control. The results predicted by preliminary anaysis of these systems indicate a significantly improved performance by the threshold system, as shown later.

THRESHOLD MODEL

In studies of human driver characteristics on a driving simulator, Barbosa (1) observed typical phase plane trajectories (plots of relative velocity as a function of headway) of the human driving a car that is overtaking a lead car in a two-car situation of the form shown in Figure 1. These trajectories are typified by two basically different regions (or modes) of operation. In the first region, for $v = v_1 - v_2 < < 0$ and the lead car velocity v_1 equal to a constant, the driver is found to maintain velocity v_2 of the trailing car equal to a constant until the headway diminishes to a value below a certain reference level, or safety threshold. At this point the driver takes action by decelerating, thus reducing the relative velocity v to the vicinity of zero. As might be anticipated, with increasing values of initial relative velocity, the values of the reference level of headway at which the driver initiates action become greater. In the second region, for $v_2 \cong v_1$ and v_1 = constant, it is found that the headway oscillates in a semi-random fashion about some mean value of steady-state headway. This latter region is presently being investigated on a statistical basis by Todosiev (2). The model of human driver performance in this region has been termed variously as the "decision point

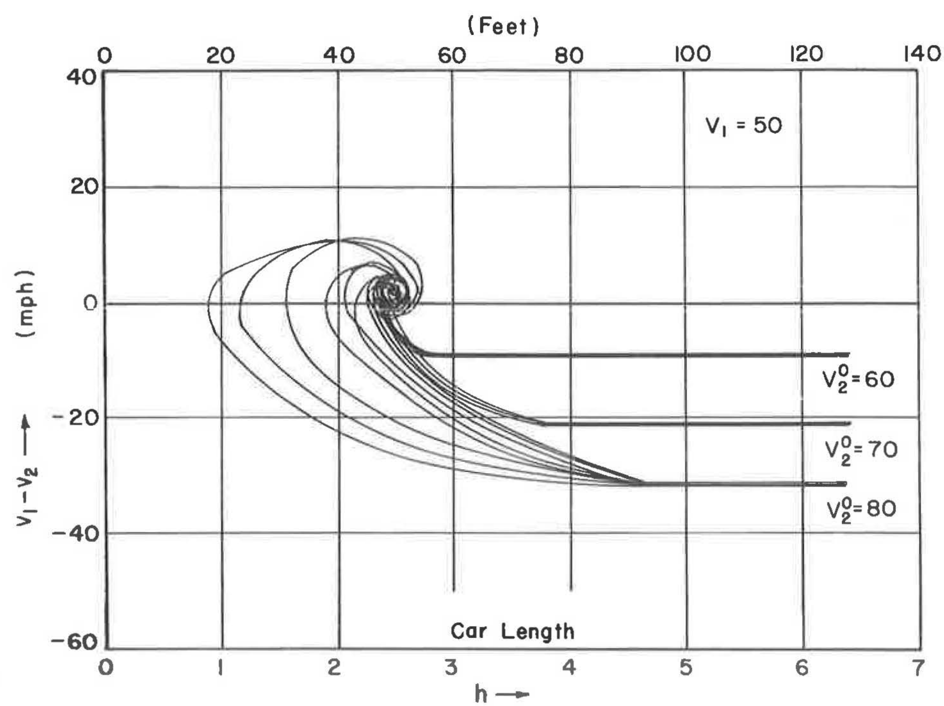

Figure 1. Phase trajectories of human driver overtaking lead car in automobile simulator.

model" or, more recently, as the "action point model." The statistical studies to date have disclosed that the periodicity and amplitude of oscillations are semi-random. As of this time, a deterministic mathematical expression of human driver performance has not yet been achieved. However, data of these statistical tests suggest that the human driver is, on the average, performing as a threshold device.

An automatic control system, based on the decision point model, that has been termed a multi-mode relay control system is presently under study.

The principle of this system was derived from human driver performance in the following manner. The human driver apparently observes a changing condition of v and h as he overtakes a lead car. When the danger level becomes too high, he decelerates. In the synthesis of the automatic system the supposition is made that the "danger level" is directly proportional to the magnitude of a constant deceleration needed to bring the car to the same velocity as that of the lead car at a fixed distance behind the lead car. For a given rate of closure, the danger level increases as the headway decreases, because in stopping within smaller distances higher decelerations are needed. To be quite specific, it is assumed both that the driver always wants to use the same constant deceleration A and that he desires that the minimum headway of the maneuver be one that he would maintain in the steady state. This minimum headway is denoted K for now. When the headway decreases below that for which the deceleration A will alleviate the condition (return v to zero) with a minimum headway K, the situation becomes too dangerous, and the driver will decelerate at A. An automatic system can be made to do this.

Assuming that the relative velocity and headway can be measured by the equipment in the following car, this same equipment can calculate the headway H needed to reduce v to zero with final headway K.

$$H = g(v) = K + \frac{v^2}{2A} \tag{2}$$

in which

$K = h_{ss}$ = steady-state headway;
v = relative velocity; and
A = acceleration constant (or level).

As the measured headway h becomes less than H, a relay is switched which activates a brake actuator to give a deceleration A.

The preceding concepts are shown in Figure 2 for the case of one switching function (or level of danger) with $A = A_1 g$. From this figure the headway h diminishes at constant relative velocity until the headway error signal ϵ_h becomes slightly negative. At this instant, the trailing car decelerates with a constant deceleration of $A_1 g$ along the $A_1 g$ relay switching function (path A) until v becomes zero at $K = h_{ss}$. However, it is possible because of physical circumstances that the trailing car might not decelerate at exactly $A_1 g$. If the actual value of deceleration were slightly greater (such as $A_2 g$), the actual trailing car trajectory would be along path B, or if slightly less (such as $A_3 g$), the actual trajectory would be along path C.

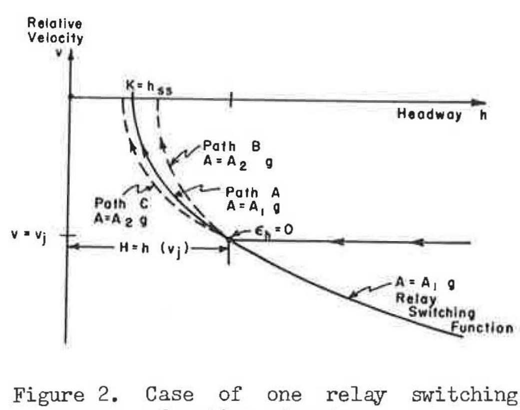

Figure 2. Case of one relay switching function, $A = A_1 g$.

This latter situation suggests then that a practical implementation of this system should have at least two or more different relay switching functions (or levels of danger). The lowest level of danger is represented by the smallest value of constant deceleration, whereas the greatest level of danger necessary to avoid a rear-end collision is represented by the largest value of constant deceleration. This

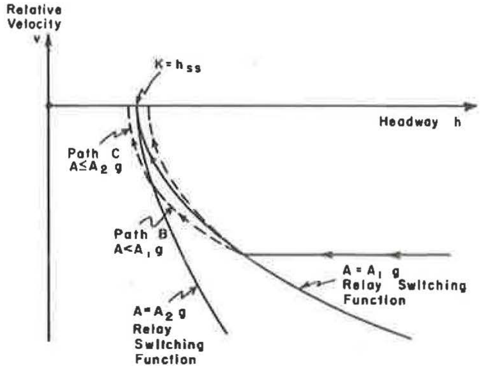

Figure 3. Case of two relay switching functions, $A = A_1 g$, and $A = A_2 g (A_2 \simeq 5A_1)$.

situation is shown in Figure 3 for the case of two relay switching functions with decelerations of $A_1 g$ and $A_2 g$. If in the $A_1 g$ mode, the actual deceleration is less than $A_1 g$, the actual trajectory taken will be along path B until intersection occurs with $A_2 g$ level of greatest danger. When this occurs, the deceleration of the trailing car steps to A_2 (or approximately thereof) along path C, thus averting a potential collision course along path B in the absence of the $A_2 g$ switching function.

A preliminary analysis of a multi-mode control system with three levels of deceleration and one level of acceleration has been performed. The three levels of constant deceleration chosen were 0.02 g (neutral gear), 0.1 g (brake actuation), and 0.5 g (brake actuation), and the one level of constant acceleration was set at 0.1 g. These values are compatible with the vast majority of motor car capabilities under normal circumstances. A block diagram of this control system, along with means of calculating the relay switching functions from v and h, is shown in Figure 4. Some of the results of this analysis are shown in Figures 5 and 6. From Figure 5, it is found that the multimode control system is capable of averting a rear-end collision starting from the large-signal (or transient) situation; in addition, a stable limit cycle is established in the vicinity of zero relative velocity. The latter is accomplished by having the control system drop out of the deceleration mode and into the 0.1 g constant acceleration mode at a threshold relative velocity of $v = +2.5$ mph. The maximum headway amplitude of the stable limit cycle was found to be about 15 ft, with a period of oscillation slightly less than 15 sec.

In the region of small values of relative velocity v and headway close to the desired steady-state value, it may be desirable to switch into a linear velocity tracking mode rather than go into the nonlinear stable limit cycle. Large disturbances outside the bounds of this linear region (of the phase plane) would then return the system to its nonlinear threshold modes. The ability of this system to handle a large disturbance from the steady state is shown in Figure 6. In this instance, it is assumed that, while in the stable limit cycle (v_1 = constant), the lead car suddenly undergoes a large deceleration of 0.5 g. When this occurs, the trailing car is thrown out of the limit cycle, and its resultant trajectory is as shown in Figure 6. Along path A, the sense of the relative acceleration a is such that the trailing car is accelerating toward the lead car at 0.48 g. The same is true along path B except the acceleration is equal to 0.4 g. Along path C, the relative acceleration is zero [$a = a_1 - a_2 = -0.5 - (-0.5) = 0$] and the relative velocity v is constant. At the end of path C, the lead car velocity v_1 finally becomes zero, which means that the trailing car decelerates toward zero relative velocity at a safe value of headway. The headway amplitude required for these maneuvers was found to be about seven car lengths (approximately 125 ft).

An essential consideration in performing longitudinal control in the two-car situation is the accuracy and time lag involved in processing relative velocity and headway information to the trailing car. This matter is of importance whether the headway error signal ϵ_h be used to trigger a display presented to the human driver, or whether ϵ_h be used to actuate an automatic control system. The detection and subsequent calculation of v and h as presently conceived is based on the concept of propagating zones of influence behind the lead car. If the trailing car is at a headway less than some critical value, then the trailing car will be within the influence of the lead car. As a result, a sequence of voltage pulses of fixed amplitude and varying time base are transmitted to the trailing car by means of a communication link. From these voltage pulses, the relative velocity and headway are calculated in the trailing car. Figure 7 shows that time t_b at which the zones are reset are inversely proportional to the lead car velocity v_1, whereas the times T_0 are directly proportional to headway h.

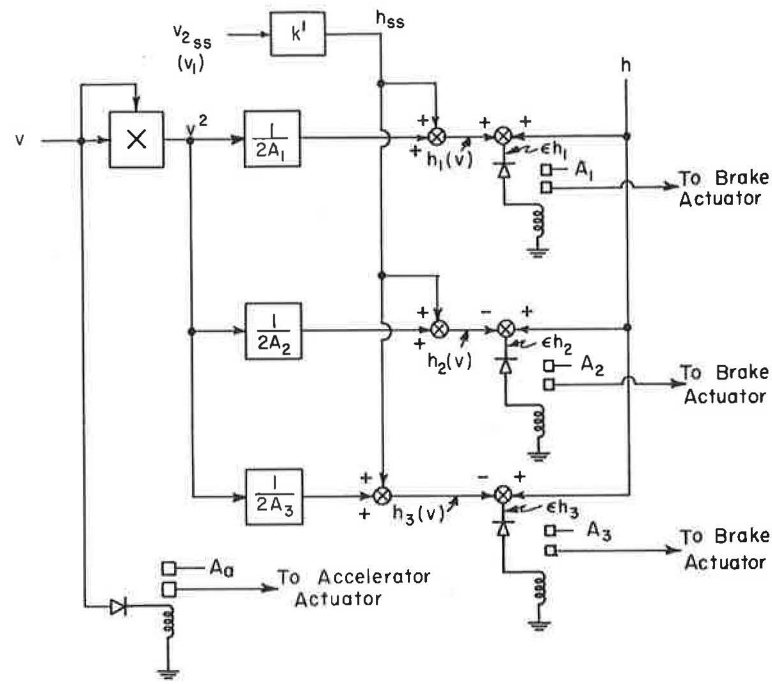

Figure 4. Multi-mode relay control system.

One means of performing the necessary calculations which has been studied in some detail is shown by a simplified block diagram (Fig. 8). This computing system, although comprised of analog and digital computing components, is basically analog in character. On the basis of the preliminary analysis, the steady-state response (v_1 = constant, $h = h_{ss}$ = constant) is good; that is, small amplitude errors and little time lag. However, for the large signal transient cases of either (a) v_2 = constant, and v_1 suddenly changes rapidly, or (b) v_1 = constant, and trailing car just enters zone of influence of lead car, the amplitude errors and time lags become rather large.

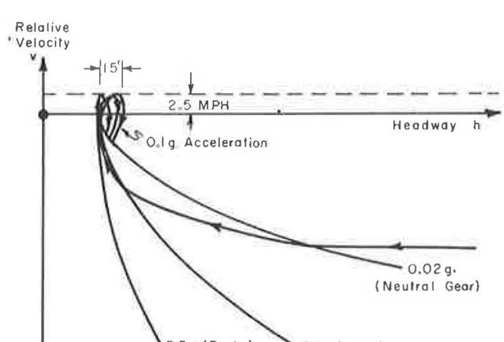

Figure 5. Phase-plane trajectories of multi-mode control system with three levels of deceleration and one level of acceleration.

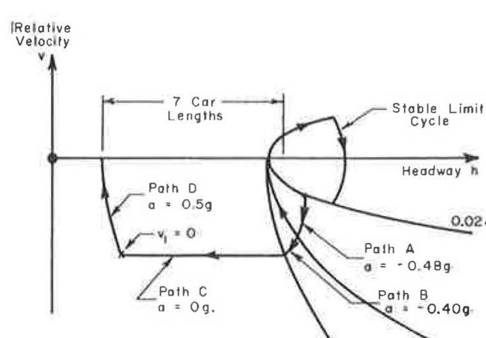

Figure 6. Phase-plane trajectories of a large disturbance from steady state.

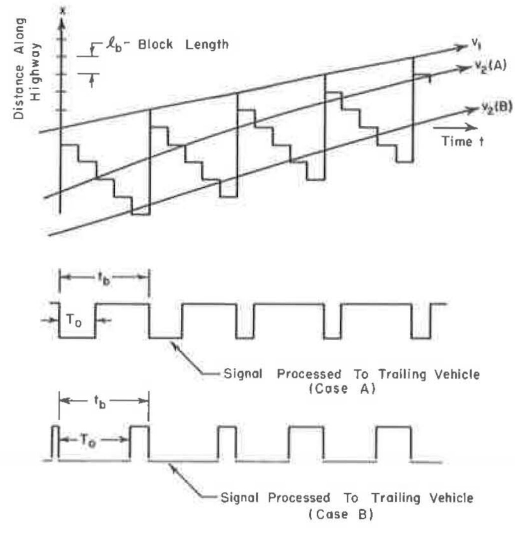

Figure 7. Signals processed to trailing vehicle.

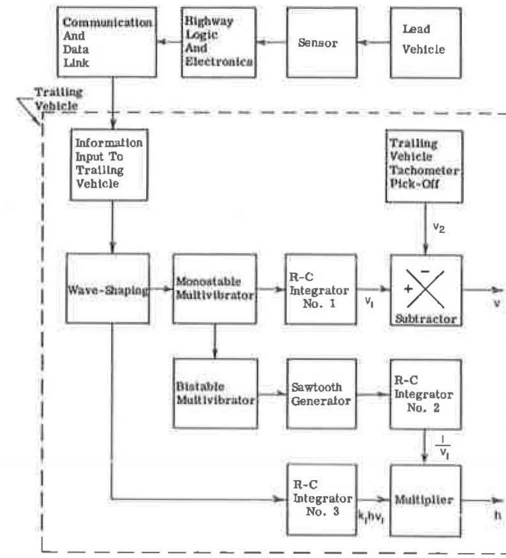

Figure 8. Analog computing system for calculation of relative velocity v and headway h.

An example of the first situation is shown in Figure 9, in which it is assumed that before t = 0 the lead car velocity v_1 was constant at 100 ft per sec. At t = 0, the lead car is subjected to a constant deceleration of 0.4 g for a period of about 5 sec. The actual instantaneous value of v_1 and the value of v_1 as calculated in the trailing car are also shown in the figure.

COMPARISON OF THRESHOLD AND CONVENTIONAL LONGITUDINAL CONTROL SYSTEMS

The simplest automatic longitudinal control system examined is one in which zones of influence are set up in the highway as in the threshold system described in the preceding section. However, the signal used by the controlled car is simply the "on-off" signal received from passing over actuated and nonactuated highway blocks. The criteria differential equation of control (2) shows the influence of the lead car on the following car:

$$\tau_a a_2(t) = - v_2(t) + V_2\left(1 - [1 - v_1(t)h(t)]\right) \tag{3}$$

in which

τ_a = effective time constant of controlled car; and
V_2 = desired steady-state velocity in absence of lead car.

This equation means that as the lead car velocity and/or the headway is reduced, the following car's velocity (taking into account its inertia and friction) is reduced from the steady-state, open-road velocity V_2.

Although the system is unstable so that the controlled car may not remain in the influence of the lead car in the steady state. Figure 10 shows the collision avoidance curve for the case of the controlled car (originally at 60 mph) overtaking a lead car at 30 mph. Figure 1 shows that the constant deceleration curve avoids the collision better at a lower level of deceleration than does the control system. The reason for this is that the control system at first decelerates too little, and later in the maneuver must make up for it with increased deceleration.

The performance for the same case with the threshold system is shown in Figure 11. It is adequate to avoid collisions with stability in the steady state. The figure actually

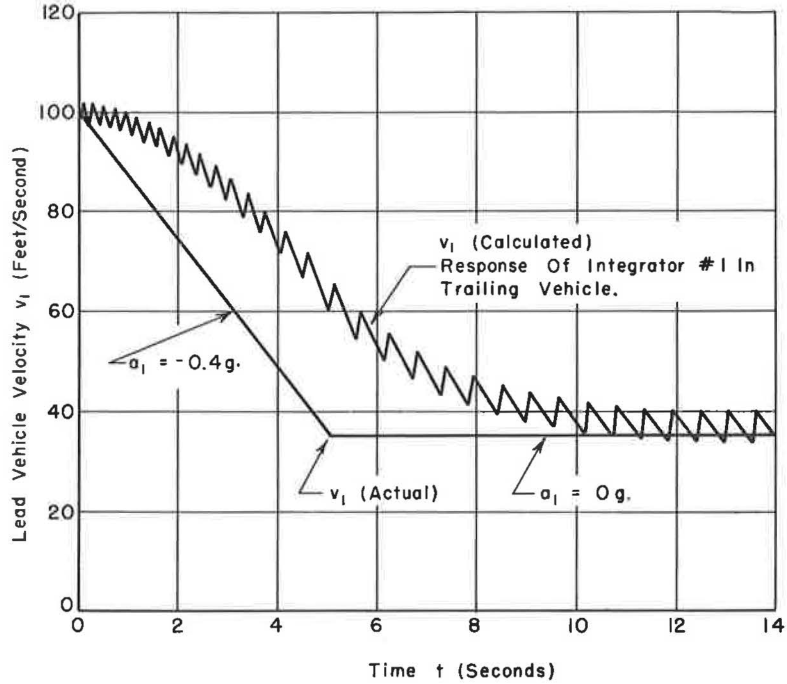

Figure 9. Actual lead vehicle velocity and lead vehicle velocity as calculated in trailing vehicle.

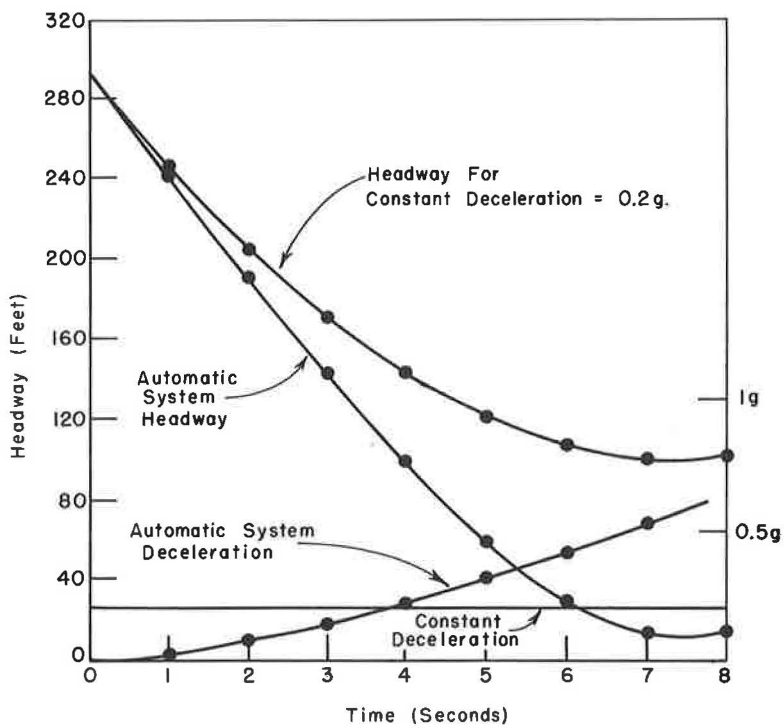

Figure 10. Simple automatic system performance.

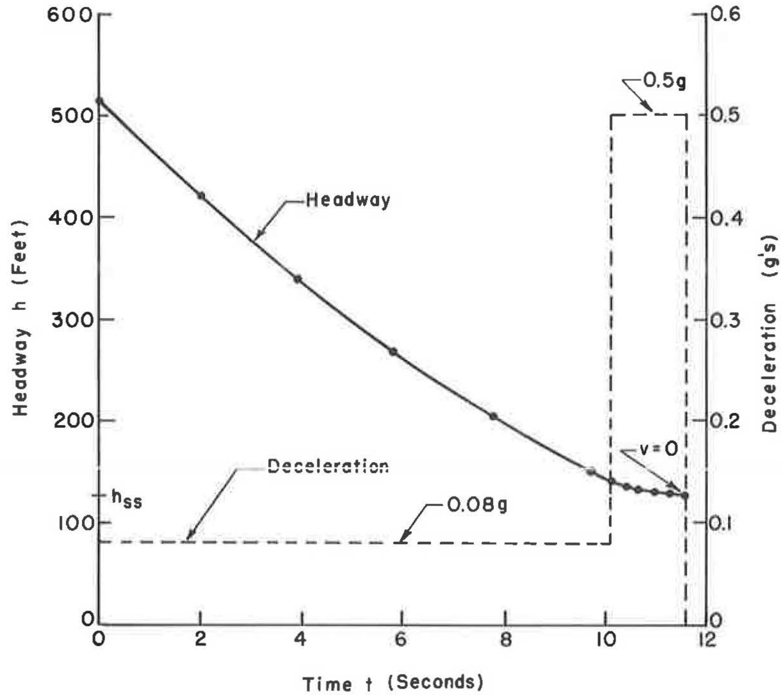

Figure 11. Performance of threshold system in avoiding rear-end collision.

shows a worse case, where the controlled automobile's brakes are not producing the required nominal 0.1 g of deceleration. Because of this, the car undergoes 0.5 g of deceleration for a short period. If the car's brakes were properly adjusted to give at least the nominal 0.1 g, the collision would be avoided with a final headway of 125 ft and the deceleration would never exceed 0.1 g. This is similar to the constant deceleration cases in Figure 10.

The analog computing system of Figure 8, although possessing large time lags in the transient situations, probably performs as well as the human does under similar circumstances. However, these large time lags are of such a nature that the complete capabilities and versatility of the automatic control system could not be realized in surpassing the performance of the human driver.

Moreover, the actual circuits that would be used to physically implement the system of Figure 8 are somewhat complex, and from the standpoint of reliability and cost, it is desirable to reduce the amount of equipment required in the car to a minimum. To these ends, a system for calculating v and h has been proposed recently in the form of a sampled-data system. Analysis of this latter system completed thus far indicates that the accuracy and time response are quite good for both the steady-state and the large signal transient regions.

CONCLUSIONS

Significant improvements were made in both the human driver description and the automatic acceleration control system when the transfer was made from continuous function driving criteria to threshold criteria. Also, study of the human driver has pointed the way to a feasible automatic system. It is hoped that as the decision point model of the human driver becomes more accurate, it will also describe the driver in the transient state, such as rapidly overtaking a lead car. This description combined with the results of a study of the best possible motion of the controlled car in the transient state should yield the optimum driving system, characterized by a reduction in rear-end collisions and higher safe traffic density.

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Long-Range Research and Development Program for Individual Transportation Systems

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A long-range research and development program for individual transportation systems is described. Three phases are outlined: systems analysis, research and development, and prototype testing. The systems analysis phase determines the basic criteria governing the performance of any system of individual transportation and develops a general systems concept. It provides the framework for the other two phases of the program.

The ultimate objective for the total program is the determination of the most promising integrated systems concepts as a basis for completion of the research from which a prototype or prototypes of individual transportation systems can be developed for evaluation. The long-range research and development program for individual transportation systems will not be accomplished in a short period of time or by any one agency. The general plan has been formulated. As the program develops, it is anticipated that there will be participation by States, industry, and other interested groups.

• THE PRESENT highway transportation system is highly effective for individual transportation. It serves the needs and desires of individuals very well. But complacency is dangerous in view of a rapidly changing technology and ever-rising standard of living. The Interstate Highway System, when completed in 1972, is expected to alleviate congestion, decrease travel time between origin and destination, and contribute to an increase in safety, comfort, and convenience for travelers. But it is important to look beyond the completion of the Interstate System. This Nation must keep ahead of the continually changing demands by improving its transportation systems to satisfy individuals needs in the future.

It should be remembered that the Interstate System, as now being constructed, is the culmination of research and development that was started more than a generation ago. To meet the needs of the future, it is necessary to intensify research and development efforts by using new technology in a coordinated and integrated fashion. Hence, the Bureau of Public Roads is proposing the long-range research and development program for individual transportation systems described in this article.

A recent statement by Robert F. Baker, Director of the Office of Research and Development, Bureau of Public Roads, summarized this long-range program well:

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> The accelerating requirements of the Nation make clear that a systematic, energetic research and development program is essential if the optimum transportation system to meet these needs is to become a reality. This program will define a range of alternative transportation system concepts that offer substantial improvements over present concepts. Initially, the program will consist of an intensive systems analysis to develop the basic criteria governing the performance of any system of individual transportation. The ultimate objective of the program will be to determine the optimum integrated systems concepts and to perform the research needed to develop prototypes for field evaluation.

To initiate the first phase of the program, the systems analysis, a set of specifications has been prepared by the Bureau of Public Roads after consideration of the many alternatives suggested by industry, university, and other transportation specialists. The long-range research and development program for individual transportation systems will not be accomplished in a short time or by any one agency. Public Roads has formulated the general plan and proposes to undertake the initial phases of the program. As the program develops, it will broaden to include participation by the States, industry, and other interested groups.

NEED FOR PROGRAM

The program described has been evolved from an examination of individual transportation; that is, systems designed for individuals to move themselves or their possessions under their own control. This examination was especially related to the ways in which individual transportation may significantly change to meet the needs and requirements of a society that is itself undergoing rapid change. The program was developed because of the recognition that no transportation system can be permitted to drift, with the hope that it will be adequate indefinitely. No society so dependent on personal mobility can afford such luxury. Hence, this program is concerned with the long-range future of individual transportation.

It is obvious from any examination of the highway transportation system that the purposes for which it exists do not depend on the peculiar physical characteristics of that system. Highway transportation arose out of random invention and has developed as a system in large measure by trial and error. The ultimate reason for the dominance of the highway transportation system over other transportation systems lies in the fact that it better meets the needs of people for movement today. Highway transportation offers the individual the freedom to (a) adapt his travel to a set of time criteria determined by himself, (b) expand the area that he can use to satisfy his particular needs, and (c) schedule travel according to his own plan and order of priority. Therefore, regardless of the mechanical methods employed, the objective of any system of individual transportation is to provide maximum freedom of movement so that the greatest possible number of people may satisfy their independent and individual needs for travel and for movement of goods.

MANY CONCEPTS POSSIBLE

It should be recognized that highway transportation is only one possible system concept of a tremendous variety of possible concepts that can be employed for individual transportation. Figure 1 shows it to be only one system of a surface-space transportation concept. An air-space concept, of which the ground-effects systems are an example, also is possible, as is a time-space concept, of which closed-circuit television is an example. In addition, there may be other concepts that have not been considered, as well as systems formed of combinations of all. Consideration of these concepts poses questions as to whether (a) systems embodying them are technologically possible; (b) how the alternatives are to be defined; and (c) how determinations can be made as

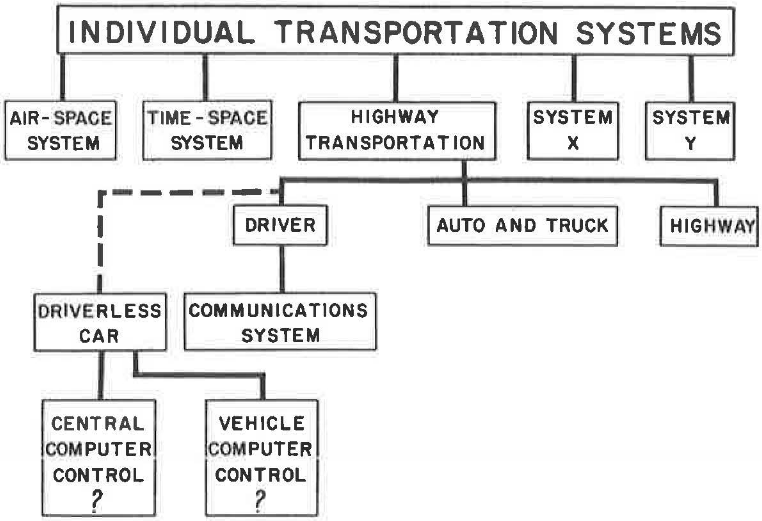

Figure 1. Highway transportation—one system for individual transportation.

to the feasibility of these concepts, and whether the resultant transportation systems would offer measurable improvement over the highway transportation system now available. Many answers to these questions have been and are being suggested. Most, although not all, suggest modifications of the present highway transportation system. Some of the other answers include suggestions for pallet systems or ground-effect systems.

Highway transportation, which may be considered as a system because it operates as the result of the interaction of the three elements of driver, vehicle, and highway, has stimulated suggestions interesting because of their emphasis on one aspect. Almost all suggested modifications have pertained to the driver or, stated more generally, the control mechanism. Suggestions have ranged from driverless automobile systems to complex communication systems.

Although improvement of the existing system by use of sophisticated electronics or mechanical means in the control subsystem is necessary, it is frankly not known whether simply superimposing various devices on highway transportation can ever meet the long-term needs for individual movement. For example, is the control of the vehicle now so poor that new control systems must be added? If so, what kinds of systems? Shall there be a large central computer, which controls groups of vehicles by telemetry, or a small one located in the vehicle? Technologically, use of any of these techniques is possible, but which is the most efficient technique and how can efficiency be defined? Which technique is most reliable and how is its reliability to be measured? Which technique is the safest and how can its safety be proved?

Further, can an optimum solution to the problem be obtained without consideration of the design of other aspects of the highway transport system? What of the vehicle? Can the existing vehicle be modified or can a novel one be substituted that could be controlled more easily or more economically? Can the highway be designed to eliminate control problems? Each of these separate questions may be answered in more than one way. However, it is becoming increasingly obvious that over the long run, a significantly improved system cannot be obtained by treating its parts separately. To achieve a radically improved system of individual transportation, a complete and integrated system must be conceived, designed, and developed. This cannot be done by arbitrarily pursuing any one particular electronic or mechanical technique. Although this approach has been the historical precedent, such a procedure precludes valid comparisons and objective choices among the many possible alternatives.

LIMITATIONS OF ARBITRARY APPROACH

The limitations of pursuing one electronic or mechanical technique become very evident from a brief analysis of some proposed solutions to the control problem. For example, as shown in Figure 2, induction radio has been developed and is being suggested as a means for transmitting control information to the driver or his equivalent. Another suggested solution involves a system of detector units placed in the roadway that would form electronic blocks for the location of vehicles. However, it should be obvious that to use either of these devices in this manner would imply that a whole set of decisions had been made about the nature of the control problem and its solution. Thus, the use of induction radio techniques would imply a decision to use a system of radio frequency for information transmission rather than some kind of pavement-coding system. It would also imply that a decision has been made about telemetry and radar. In addition, a decision to use induction radio rather than a specialized central computer system would indicate a conclusion that in-auto computers are the way to solve the control problem. Finally, all of these decisions clearly would assume that electronic methods should be used to resolve the control problem.

However, within current limits of understanding of the true nature of the control problem, can mechanical methods of solution be ruled out? Further, can the current solution to system control—the human—be ruled out? After all, the human has capabilities that are difficult to rival mechanically. For example, the human can detect angular velocities as low as 5×10^{-5} radians per sec; he can discriminate differences in frequency to an accuracy of 0.2 percent; he can estimate position relative to himself with an accuracy of 1 percent. These capabilities not only are unusually good but cost nothing to produce.

This discussion of just one aspect of the highway transportation system shows the tremendous complexity of the problem and the dangers that may arise from the arbitrary choice of one type of solution. This danger obviously applies to all the other aspects of the system. To operate in this arbitrary fashion would minimize the chances of ever knowing whether an efficient system had been selected.

The problem of individual transportation can be resolved only through a systematic

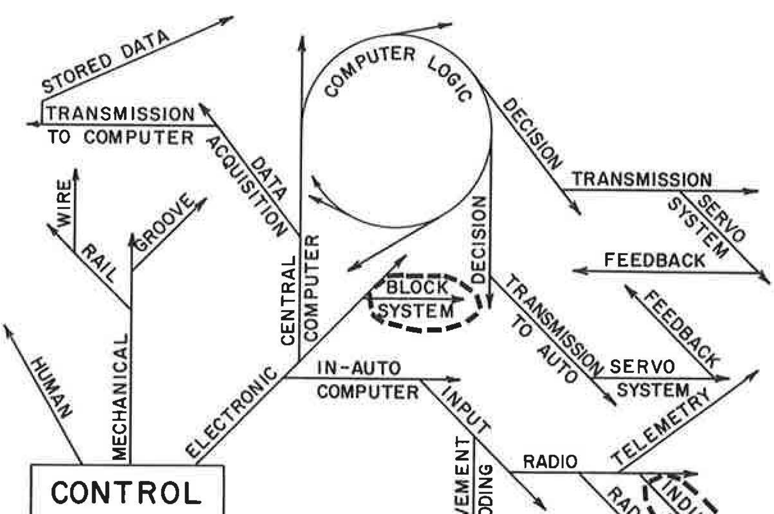

Figure 2. Possible solutions to control problems.

analysis that starts from the essential requirements that any system must have to meet the objectives of individual transportation. Only from such an objective analysis can measures be developed to evaluate alternative physical means rationally so that the most effective systems may be selected. To achieve this selection a comprehensive and integrated program of research and development is required. Such an approach, which is the modern systems engineering approach, is the one that the Bureau of Public Roads proposes to use in the solution of the long-range problems in individual transportation.

THE PROGRAM

The proposed program consists of three phases as shown in Figure 3. The first phase is a systems analysis, which will provide a framework for the next phase—an intensive research and development effort which is aimed at producing in the third phase one or more prototypes for testing. The initial phase of the program, the systems analysis, is a procedure for defining a complex problem in operational terms. In this way, the problem may be stated in analytical terms, thereby permitting the precise definition of alternative systems, which can be designed and evaluated. Thus, the systems analysis will form the framework for the research and development phase.

The research and development phase of the program will encompass investigations of the various components of each of the alternative systems, particularly, their interaction. A continuing process of evaluation will be used to determine whether the alternative systems selected meet the required performance criteria. Among other matters, economic considerations and questions of reliability and public acceptability of the systems will be investigated. After evaluation and research have been done, an intensive development effort is expected to make it possible to provide one or more prototype systems for testing.

Research, development, and evaluation will be a continuous and simultaneous process and considerable interaction is expected among these activities. From these feedback processes, it becomes apparent that the research and development phase will be modified as the systems analysis proceeds. Likewise, the systems anlaysis will provide a general but flexible framework for the research and development phase.

The third phase of the over-all program will consist of testing one or more prototypes that have been produced during the research and development phase. This testing will be undertaken on a proving ground before the prototype is subjected to field tests. Again, there will be feedback between proving ground and field tests.

Similarly, the three phases of the over-all program are interdependent; and, as mentioned earlier, the research and development phase will undoubtedly be modified from that which is initially selected. Thus, the systems analysis will, in effect, be modified as research and development proceeds. Similarly, modification also will occur from research and development to prototype testing. It is, therefore, conceivable that feedback from prototype testing to the systems analysis could revise the initial systems concept.

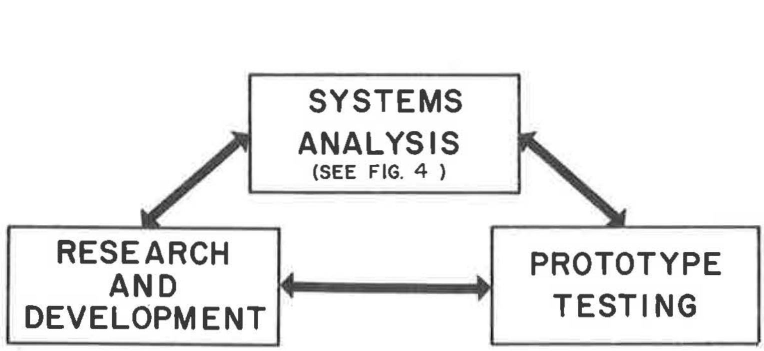

Figure 3. Interrelated phases in long-range research and development program for individual transportation systems.

SYSTEMS ANALYSIS

The first phase in fulfilling the objective of this long-range program is to conduct an intensive systems analysis. Systems analysis is described as the definition of a problem in operational terms, which then permits formulation of a systems concept. The problem is individual transportation, and the goal is to define this transportation system, formulate requirements for it, evaluate and select the most promising systems concepts, and plan for the subsequent phases.

This systems analysis will be essentially a theoretical, analytical effort by a team of engineers and systems analysts. It will not involve physical hardware or its application. It will involve the general or abstract principles of individual transportation. It will formulate mathematical models that present a clear, systematic picture of individual transportation.

This will be the first time that such a comprehensive systems analysis of a transportation system has been undertaken. Its output will provide a better understanding of the over-all problem, a logical grasp of the most promising concepts, and identification of critical areas of needed research.

Figure 4 shows that the analysis will consist of three parts: a definition of performance requirements that the system must meet, the formulation of a generalized system concept, and a description of the alternative systems that may be derived from the generalized concept. The first two steps will constitute a purely theoretical study. The general model or concept of individual transportation to be formulated will be the most important, single product of this effort. The alternative systems shown at the bottom of Figure 4 will then follow.

At this point it should be added that the relevant user categories that one thinks of today will be considered in the systems analysis. These categories are the transportation of individuals; the mass transportation of people, covering also the movement from origin to the mass transport vehicle and from such a vehicle to a destination; and the transportation of freight together with the special characteristics that such transportation requires.

Performance Requirements

As the first step — definition of performance requirements — a preliminary set of system requirements must be drafted in the early stages of this analysis. Such requirements will be the "guide posts" for the basic evaluation of proposed systems. It should be understood that they are preliminary, however, for they will be continually modified

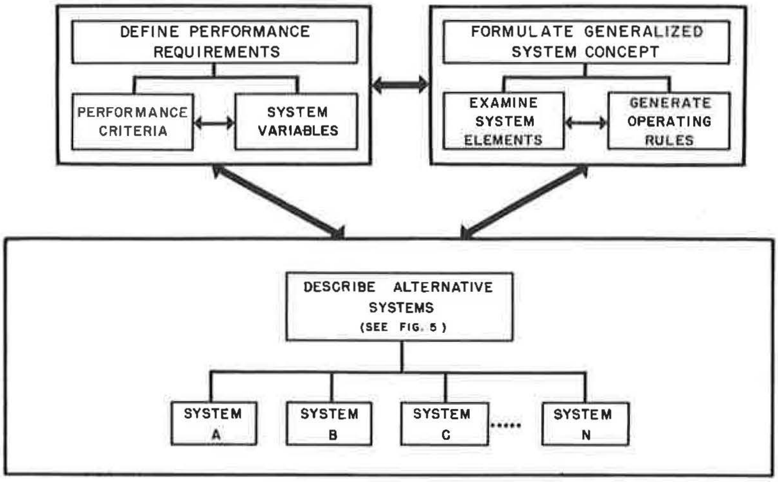

Figure 4. Outline of systems analysis for individual transportation.

as the program progresses. Experience has shown that formulation of these requirements is a process of achieving a harmonious balance between practical means and ideal goals. A sound requirements statement is therefore an end product of the systems analysis even though in preliminary form it is used for guidance of the study itself.

The statement of performance requirements will define performance criteria that are the measures by which individual transportation can be judged. It will also define the variables or quantities of such a system and their range of values. Some examples of criteria might be the probability of collision, the predictability of position, or the travel time between origin and destination. There may be many others similar to these. There may be other ways of specifying them. However, the criteria must define the system on a complete and rational basis. The variables, and their operating ranges may include such items as speed, flow rate, and size of vehicle. Again, these are only examples of the qualities that describe the operation of a generalized concept.

As to the formulation of the generalized system concept, it should be noted that this concept is still completely theoretical and will be based on the performance requirements to be developed.

First, an examination will be made of the essential elements or components of any transportation system. These components include the vehicle, an operating medium, the control logic, and the human. The human, of course, must be considered both as a part of the control logic and as a system user. In each, there are various alternatives that might be listed in the light of present and future technology. The interaction of these four elements is highly critical.

Then, operating rules will be generated. These are to be the bases by which the characteristics of individual transportation may be specified in terms of the performance criteria and system variables. These are the theoretical expressions of a generalized systems concept. The operating rules may be expressed as a set of equations and the variables could then be related in such a way as to meet the defined performance criteria. Thus, it could be that a description of individual transportation would be stated as a set of mathematical functions.

Once this generalized framework for individual transportation has been developed, any combination of vehicle, operating medium, and control logic can be tested. Ultimately, one or several of the possible combinations that best satisfy these equations will be chosen for more intensive analysis. This is not a simple, straightforward procedure; there must be feedback and interaction among the various steps. The generated operating rules and the several alternative solutions will point to the competence of the original performance requirements. Conversely, the continuous refinement of this performance statement must be accurately reflected in the operating rules.

Because this feedback process is of such vital importance to a systems analysis, the analysis can become extremely complex, particularly when dealing with a system so encompassing as individual transportation. Moreover, the systems analysis will form the basis for the entire long-range research and development program. Hence, it is evident that the systems analysis should be done as a single operation in order to provide a solid framework around which all succeeding steps can be taken.

Precaution must be taken to avoid initial error, because any concept adopted and implemented would undoubtedly involve a significant portion of the national effort. To prevent hasty judgment and preselection of the most obvious (or any other) form of individual transportation as the "only" solution, it is desirable to explore all alternative concepts that could possibly meet the same objectives. Therefore, the systems analysis must investigate feasibility from broad viewpoints and determine the detailed technical concepts worthy of further research, development, and evaluation. It will define various alternative system concepts, bring them into a common analytical frame of reference, and compare their relative effectiveness.

One result of the systems analysis, incidentally, might be to indicate that modification of the existing system is the optimum way to proceed in the research and development phase. But, if this is the case, it will be clearly established that other alternatives have been investigated and rejected, and the reasons for such rejection will be detailed. Thus, it has been shown that by a systems analysis of the criteria, the

variables, and the components, one arrives at a theoretical expression of individual transportation. For the first time there will be a comprehensive model of a major transportation medium from which to select optimum solutions. This generalized concept will permit the preliminary testing of many individual system combinations and the selection of those that best satisfy the general expressions.

Alternative Systems

Figure 4 shows that the three interdependent operations comprise a theoretical systems analysis. A general procedure was outlined for defining the performance requirements and formulating a generalized system. Now the third operation, the description of alternative systems, is discussed. However, these three operations are interdependent and must therefore be undertaken as a carefully coordinated effort.

By way of definition, an alternative system is the combination of operating components that will accomplish a given objective in an acceptable manner. In this case, describing an alternative system means proposing a complete solution to the problem of improving individual transportation. By this process, several alternative systems, not just one, may evolve. But, a properly conducted systems analysis will produce the minimum number of maximum efficiency systems. Each system will be complete and can be accurately described.

These alternative systems, as shown in Figure 5, obviously cannot be named at this time. However, they might include such systems as the often-mentioned but so far vaguely described "automated highway." One system might be a conveyor belt highway and another might be some form of pneumatic tube transport. Or, with visions on the horizon of the possibilities of the future, one system may utilize airborne vehicles guided by laser beams and propelled by the energy received from the lasers. Other systems concepts will complete some unknown number of alternatives.

Figure 5 shows that there will be a description of the operating characteristics of each alternative system, which will describe how the components within that system interact. The subsystems of which any system must be comprised will be described from all aspects. In this description, consideration of the environment will include

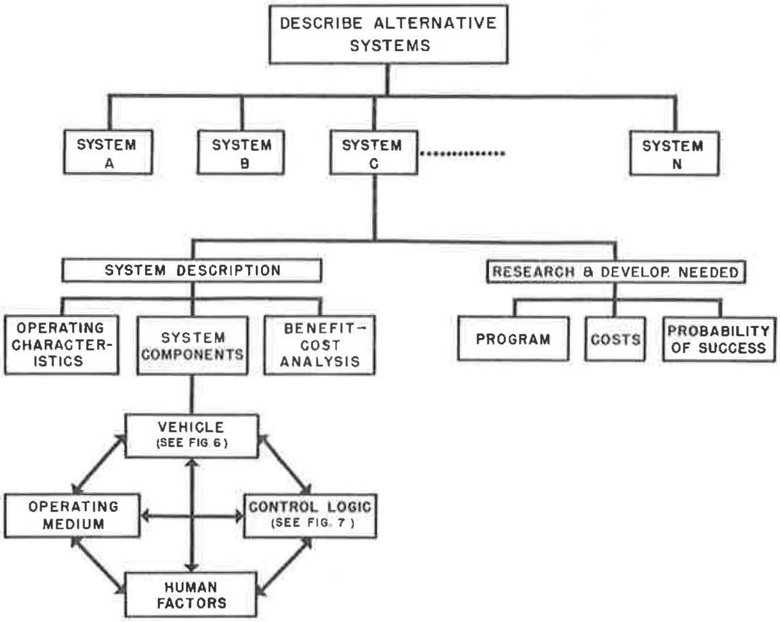

Figure 5. Description of alternative systems including research and development needed.

analyzing the features of the areas through which the system itself will operate, such as the land areas of the business district, the city, the suburbs, and the rural areas. It will also include solutions for those problems of entrance, exit, and storage of vehicles within the system. And, of course, it will describe the effects of environmental problems such as weather.

The subsystems will be described from the viewpoints of the various user groups. Of these, the largest group will consist of those who are desirous of improved personal transportation. But full consideration will also be given to that group of individuals who wish to join with others to share improved mass transportation; and to a third group, which will include those individuals who desire to improve the movement of freight. There will also be a description of the probability of acceptance of each given alternative system. This may well be based on a description of its comparability with the present highway system or it may use some other datum for evaluation. It will, of course, include a complete description of the readjustment necessary in the economy to accept the new and proposed systems.

Figure 5 also shows the four categories of basic components in any transportation system: the vehicle, the operating medium, the control logic, and the human. Close interconnection must exist among all four of these component categories. It is not feasible to develop one of the components without full consideration of the others.

The vehicle will be considered as a container for that which is to be transported. In each alternative system the vehicle will be comprised of some combination of power sources and propulsion techniques, as shown in Figure 6. This 2 by 2 matrix shows some existing and familiar vehicles. But many other vehicles could be placed in the

VEHICLE

		POWER AND PROPULSION MEANS	
		PROPULSION	
		SELF	EXTERNAL
POWER	SELF	AUTOMOBILE DIESEL TRAIN GROUND EFFECTS MACHINE	?
	EXTERNAL	TROLLEY ELECTRIC TRAIN	CONVEYOR BELT IMPELLER SYSTEM SKI LIFT

Figure 6. Various combinations of vehicle power and propulsion.

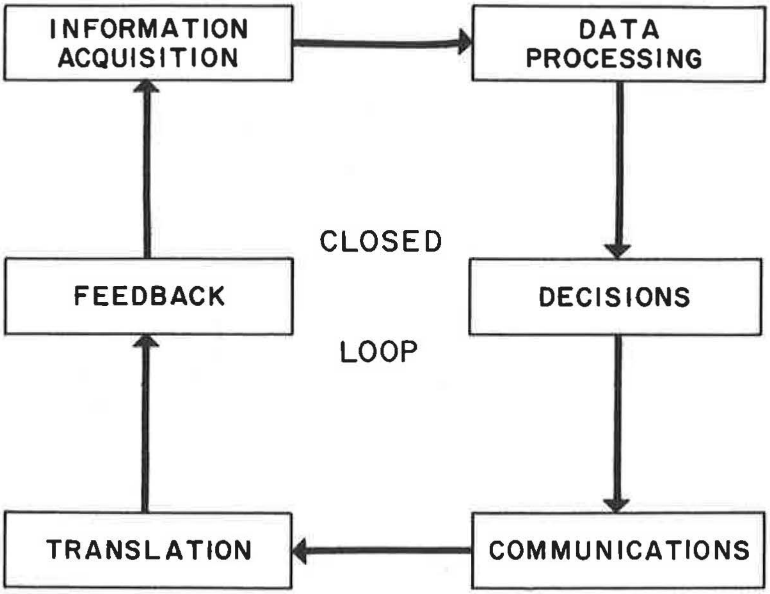

Figure 7. Control logic considered as closed loop process.

matrix. The self-powered, externally propelled vehicle does not exist at present. However, a systems analysis would generically describe new and unique vehicles that in concept may make use of such techniques, and it is entirely possible that such a vehicle could be developed. The systems analysis will describe the useful characteristics of the proposed vehicles and contrast them with undesirable characteristics such as air pollution. From such descriptive comparisons of vehicles, the usefulness of each as a system component will become evident. These will be generalized rather than detailed, technical descriptions.

The operating medium of any alternative system in this systems analysis will be described by its features as a "highway." The term highway is used in the sense of the AASHO definition, "A general term denoting a public way for purposes of vehicular travel, including the entire area within the right-of-way." As has been mentioned, the operating medium of an alternative system may well be the conventional highway, with or without some modification. However, unconventional media such as the ground pathway, various types of structures, air, and many others need to be considered and compared for the description of alternative systems. Different subsystems possibly will require different media to promote the most efficient movement of traffic in each particular area. The description of the operating medium will also indicate what provision must be made for such foreign objects as pedestrians, animals, and debris.

The control logic of a system is that combination of techniques and devices employed to regulate the operation of that system and is outlined by the closed loop diagram shown in Figure 7. For each system, the analysis will show what information needs to be acquired and how it will be obtained. The conception and design of the processing and analyzing equipment that will be necessary to convert these data into operational decisions can then be described. The best means of communicating these decisions to the mechanical equipment or the human, which will translate them into the necessary action, can be specified. The control logic loop is closed by including the reaction, or feedback, which will detect and correct the performance errors. The description of the control logic will also include such things as the handling of nonconforming vehicles, failures in the logic itself or in other parts of the system, and the accommodation of personal emergencies.

It is also evident that as each alternative system is described, the role of the human must be considered both as an active system element and as a rider. No analysis need

assume the preconceived notion of complete automation. The amazing ability of the human to accomplish perceptive and control tasks has been previously pointed out. The capabilities and limitations of the human will be studied and the results of these studies will determine the areas where he may be utilized in guidance and control. The human may well be the monitor of an automated system; or the alternative system may be designed for human control that is to be automatically monitored. The factors of fatigue and vigilance also will be completely studied and described in each alternative system.

The human as a rider in the system will have great bearing on the acceptability of the system. Studies of the tolerance of the human to motion and to changes in motion in all directions will, of course, need to be made. Also, it will be necessary to specify the training that will be required to fit the human to each new system. These and other human characteristics will bear equally with the other components on the utility and acceptability of any system to the potential user.

Finally, a benefit-cost analysis will complete each alternative system description. It is evident that in all areas it will not be possible to indicate these items in terms of dollars. However, where it is not possible to estimate an exact cost in one alternative, the same base of comparison will be extended to the other alternatives. Of principal importance, however, is that the comparative cost between alternative systems be properly made. These costs, of course, can be categorized as initial, operating, and maintenance, and the benefits can be identifiable in each system. Those benefits which cannot be expressed in dollars and cents will be expressed in such terms as comfort and convenience to the potential user.

Thus, out of the systems analysis will come a description of alternative types of systems that meet the requirements for individual transportation. In addition, the systems analysis will define the research and development needed to produce a prototype, as shown in Figure 5. Included will be a complete description of the research and development program needed to determine the feasibility of and the design requirements for a prototype system. In addition, the cost of the research will be included and the probability of success in producing a prototype for testing will be estimated. It is recognized that some aspects of such a program will be only broadly identified in the systems analysis phase but will be detailed as research and development proceeds.

From this discussion, it can be seen that the systems analysis is a logical approach to the challenge of today; namely, to lay the foundations for the rational evolution of individual transportation systems of the future.

A Multistation, Centralized Digital Traffic-Counting System

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A highly accurate, fast, economical, and convenient system for the collection, processing, and recording of traffic-count data has been devised using a digital computer as the central processing element. This paper is a description of this system, which eliminates the need for human intervention between the traffic detectors and the processed data and fills a need in the traffic engineering field. Some of the important advantages of the system are continuous data availability, reduced data-processing time, high vehicle resolution, reduced field maintenance, low telephone line costs, low power consumption, and fully transistorized modular construction. That a series of traffic counts for all the stations can be fed into a general purpose computer with no waiting period between each report is a major advantage of this system, because the processing time on the high-speed general computer is reduced to a point where the investment for the digital computer described is easily justifiable.

• A HIGHLY accurate, fast, economical, and convenient system for the collection, processing and recording of traffic-count data has been devised using a digital computer as the central processing element. This paper describes the system, which is completely automated and eliminates the need for human intervention between the traffic detectors and the processed data, thereby filling a long-felt need in the traffic engineering field.

Figure 1 is an artist's conception of the use of the centralized digital traffic-counting system for covering an entire State. Figure 2 shows the actual routing of the telephone network for an experimental setup in the State of Connecticut. The computer in question has a capacity of 60 traffic-counting stations. As shown in Figure 1, a multitude of detector types may be used as sources of information for this computer; to name a few, pressure detectors, magnetic detectors, radar detectors, and induction loop detectors. Each dot on the map of Figure 1 represents a traffic-counting station, at which one or more traffic-counting detectors may be used. The information from the traffic-counting detectors is fed through a network of telephone circuits to a central location which houses the computer.

There are various methods of data transmission from the traffic-counting stations to the centralized computer. Among the most economical methods, the party line method of multiplexing proves to be the most desirable one. By the use of proper tone-coding equipment at the transmitting end and decoding equipment at the receiving end, as many as 20 detector stations may be connected to a circuit using the party line principle. This reduces the number of individual lines that must be run to the central office where the computer is located, resulting in economy of line rental. A "voice-grade" type of telephone line is required for this service. If individual direct lines are privately owned by the State or the municipality using the equipment, the information can

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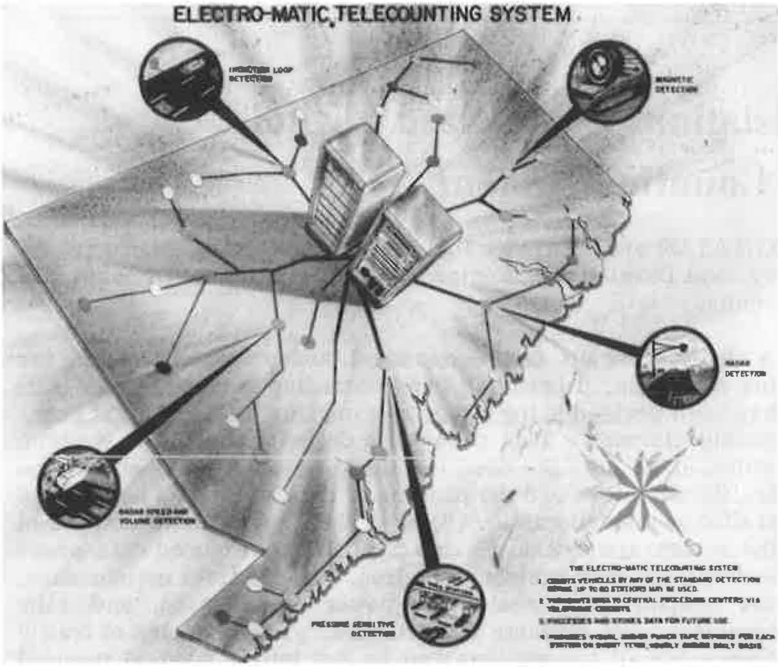


Figure 1. Artist's conception of telecount system.

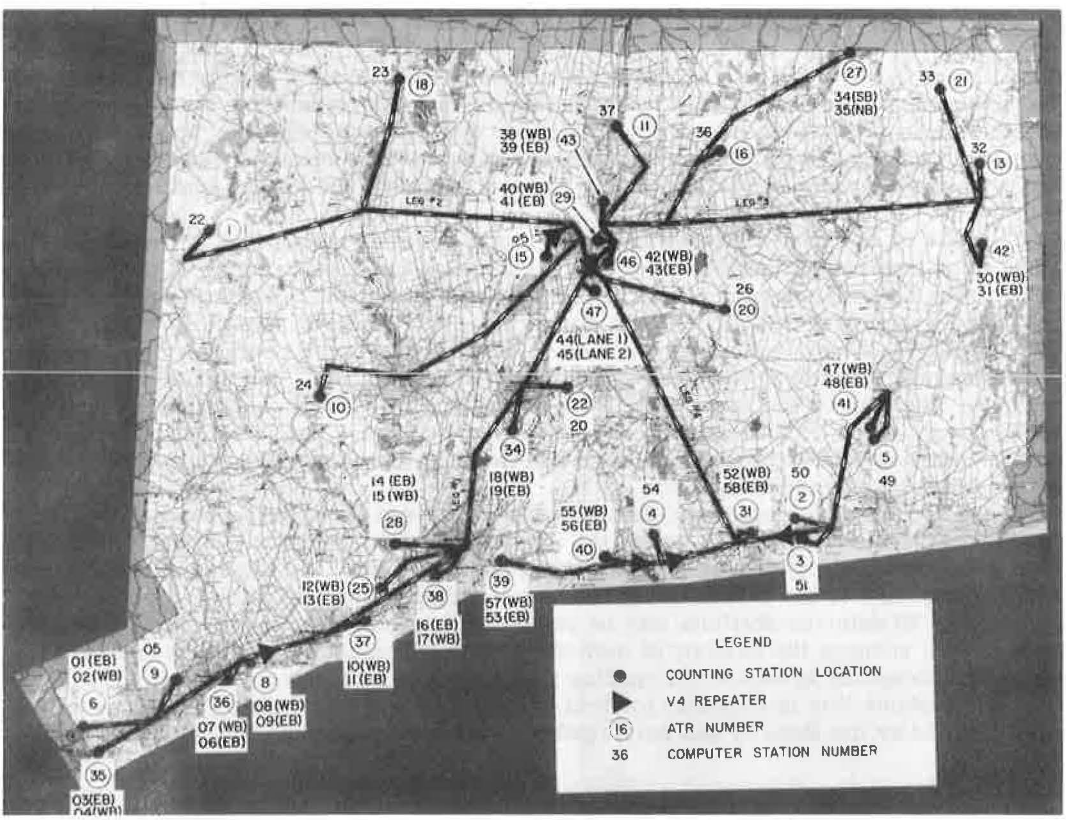


Figure 2. Map of experimental telecount system in Connecticut.

be transmitted over a pair of these lines without reverting to the use of telephone lines.

A third method of data transmission might be the use of teletype-grade telephone circuits to feed the information from the traffic-counting station to an intermediate point and code the information at this location for transmission over a voice-grade circuit. In some cases, this combination will reduce the cost of rental of transmission lines. In applications where the agency has a microwave link facility, this latter could be used, at least in part, for long-distance transmission of the data. From the terminus of the link individual circuits may be used between the decoder at the end of the microwave link and the central station. The party line method may also be used to transmit the information from the link terminal to the computer.

Figure 3 is a close-up of the three racks that house all of the necessary components or equipment that make up the traffic-counting system. The decoding equipment is in the left-hand rack. The latter may be categorized as auxiliary equipment.

Before detailing the operation of the system, the auxiliary equipment used in the transmission of data by the party line method is discussed. Figure 4 shows the scaler unit. It is normally located at the detector station. This unit has three basic functions. The first is to scale down to one any number of actuations that may be obtained from different types of detectors, or scale down to one the number of actuations produced by a number of detectors for the same location connected to the same line, providing a traffic count on a per-lane basis. To illustrate the use of the scaler unit with a few examples, it is assumed that there is a pressure detector at one location. If vehicles are being counted, the pressure detector will normally give two counts or two pulses per vehicle. This will result in double the number of actual vehicles passing the traffic-counting station unless an intermediate piece of equipment is used to count it down by a ratio of 2:1.

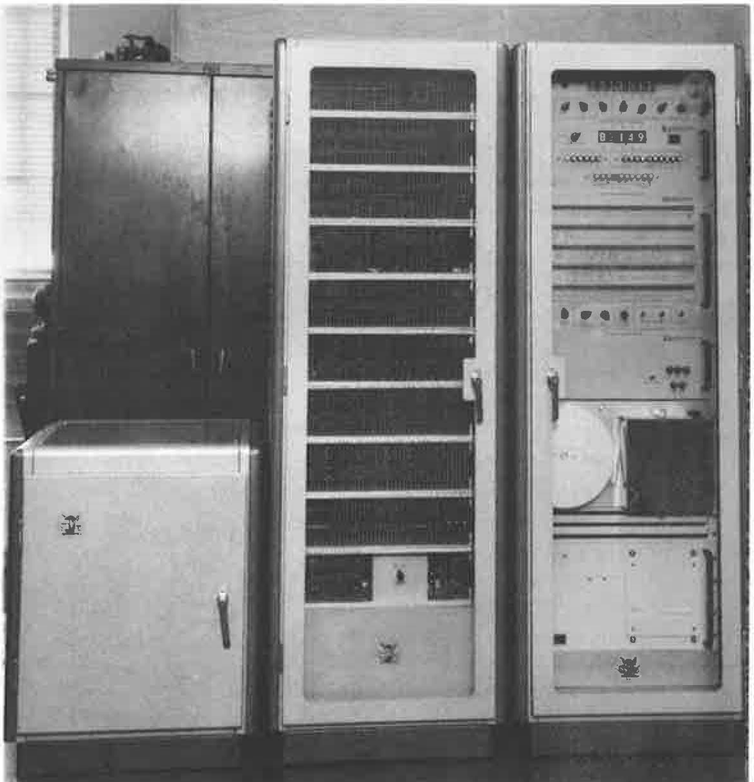


Figure 3. Central office equipment racks.

Figure 4. Scaler unit.

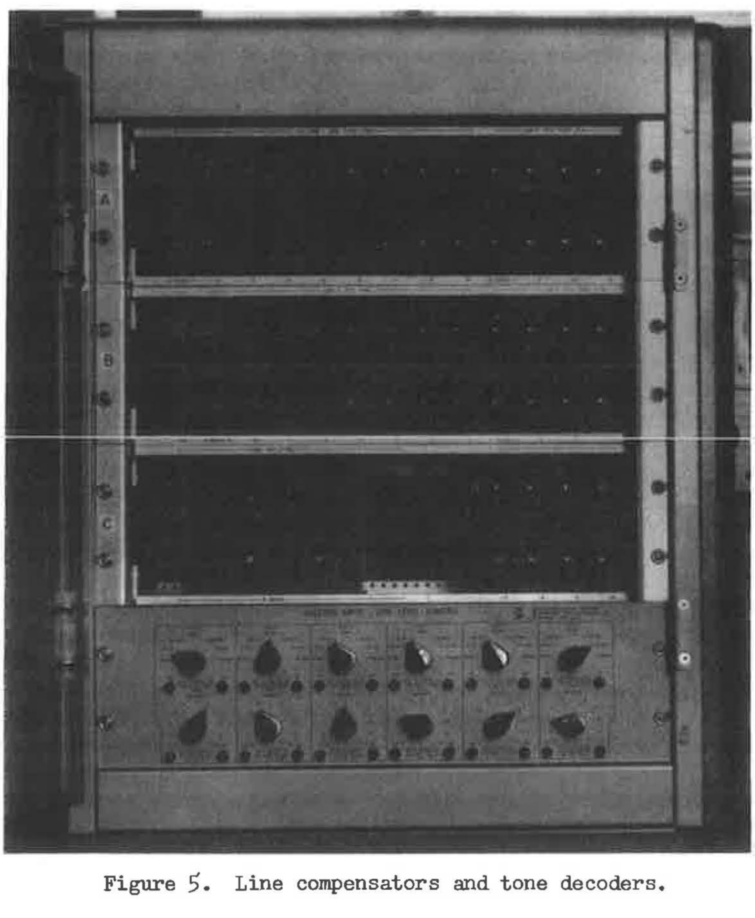


Figure 5. Line compensators and tone decoders.

In another instance, it is assumed that there is a multilane roadway with a vehicle detector in each lane. In this case, if there is no interest in the individual lane traffic count, the output of all four detectors could be fed into the scaler which would be preset for a ratio of 4:1, thus providing an average value for traffic per lane at that particular station. On the other hand, setting the ratio to 1:1 will give the total volume in both directions.

The second function of the scaler unit is to provide an output suitable for the type and method of transmission between the detector station and the "Telecount" system. By changing one of the printed circuit modules in the unit any one of three types of output may be obtained: (a) a pulse output that may be used for transmission over a teletype-grade circuit; (b) an output that will provide a relay contact closure for each traffic actuation; and (c) a tone-coded output for multiplexing on party lines. Thus, the versatility of the scaler unit makes the centralized traffic-counting system universally adaptable for operation from any type of detector as shown in Figure 1.

A third function of the scaler unit is to provide a clean output for each vehicle actuation, thereby nullifying any possible contact bounce which may be generated by the detector. Figure 5 is a close-up of the decoding equipment that may be used when the party line method is utilized. The top section of this figure shows the filter units which decode the information applied to the party line. The tone-coding equipment is designed with a response of 300 to 3,000 cycles thus allowing up to 20 stations to be connected to a multiplexed circuit. This range is within the bandwidth of a voice-grade telephone circuit.

The panel in the lower portion of Figure 5 shows the controls for a set of six compensators. These are amplifiers that compensate for the loss of signal between the transmitting and receiving points. The amplified composite signal on each multiplex circuit is fed to the tone filters whose outputs are fed to their respective input circuits in the centralized computer.

The output of the centralized traffic-counting system is in the form of a punched tape, shown in Figure 6a. This is a standard 1-in. paper tape which may be used as an input to the majority of general purpose computers. In the case of computers that do not accept a punched tape form of input, translators are available to translate the information from the punched tape to a punched card or magnetic tape. The code used for recording the traffic data is the IBM 8-channel punch tape code which is a universal code. If the computer available to the agency uses some other code, the information may be translated from one code to another without difficulty.

The output of this computer provides three basic types of reports for each station. Each station has a short-term, an hourly, and a daily report. As described in more detail later, the short-term report is the traffic count for a period of less than 1 hr, adjustable or settable from 5 to 30 min by means of a dial on the panel of the computer. At the end of each hour, the computer will also punch out automatically an hourly report for all stations connected to it. At the end of each day, a daily report, giving the daily total traffic count for each station will also be

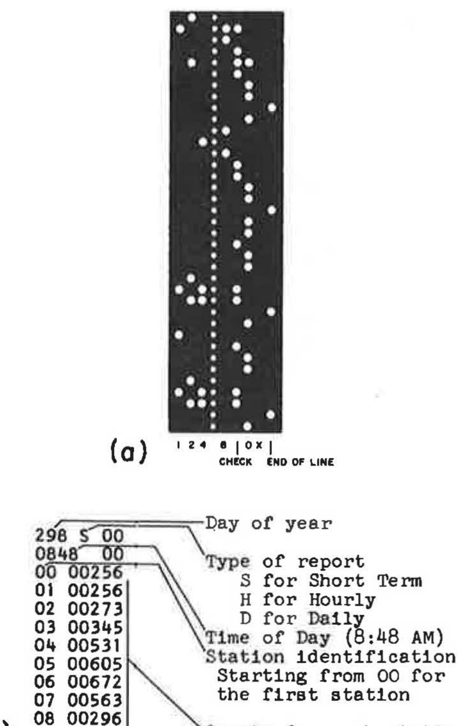


Figure 6. Output tape (a) and print-out format (b).

punched out, followed by an hourly report, as well as the last short-term report.

If the data punched on the tape are adequate for the purposes of the agency, the output tape can be run through a Flexowriter type of electric typewriter and the data printed in alphanumeric form. The format presently used in this computer is such that the report, if run through a Flexowriter, will produce a calculating machine type of report; that is, the traffic count for each station will be recorded vertically in a column. Figure 6b shows a section of the typewritten report. Every report will contain the following information: the day of the year followed by a letter such as S, H, or D depending on whether the report is a short-term, an hourly, or a daily report. The next line will be the time of the day for which the report is being printed. The first two digits indicate the hour of the day (on the basis of 24 hours), and the last two digits indicate the minutes. The third line starts with the station identification. Each station is assigned a number, the first one being designated as 00 followed by a five-digit actual traffic count for the counting period specified. There are sixty of these data lines.

Aside from the printed report, visual indication of the actual count is also displayed on numeric indicators on the display panel of the computer.

To acquaint the reader with the different components of the system, they are discussed separately. Referring to Figure 3 again, the center rack contains all of the plug-in modules. These are printed wiring board assemblies.

The rack on the right contains the larger units; i. e., the Bernoulli disk, the tape punch, as well as all of the indicating and "read-out" panels associated with the circuitry located in the rack on the left. From top to bottom, the units in the right-hand rack are the digital clock, the display and control panel, and the check-out unit. Beneath the check-out unit is the power supply. The punch used in this particular installation is the tally punch which operates only during the punch-out period. For this purpose, the punch motor is started about ½ min ahead of the actual punching period and stops right after the last data of any report have been punched out.

The heart of the system is the memory disk which is located at the bottom of the rack. The memory disk is known to the industry as the Bernoulli disk. This is an extremely reliable device due to its unique construction and special design for use in missiles. Its advantages are discussed later. This memory disk has a capacity of forty recording tracks of which only seven are presently used in this particular system. This gives some idea of the reserve capacity which is available for connecting additional input lines to the system by increasing the number of input circuits and associated hardware, and modifying a few counters.

The close-up of the individual panels in the right-hand rack provides information as to the settings of the controls. As mentioned previously, the first unit on top is the digital clock (Fig. 7). The clock produces a binary-coded decimal output for the day of the year and the time of the day. It also produces pulses at the beginning of every minute, hour, and day. The latter are used for controlling paper tape read-outs. The dial at the upper left corner of the panel enables the clock to be turned "off." In its center position, it allows the digital clock to be set manually by setting the dial for each

Figure 7. Digital clock panel.

individual digit represented and displayed in the numeric display shown in the center of the panel. The first three digits show the day of the year, the following two digits the hour of the day, and the last two digits the minutes. The third position of the dial at the left top corner of the panel is the "run" position of the clock. This is the normal operating position of this dial. The numeric display on the digital clock gives the chronological information just described at all times.

The second unit in the rack is the display and control unit (Fig. 8). Its function is to display the actual count at every station when a print-out operation is performed. In addition, a manual read-out is also possible by selection and actuation of the proper station selection button. The "read" button must then be depressed in conjunction with the type of report selector button to read either one of the three different types of report for each station. By the same token a manual print-out can also be obtained in between the scheduled print-out periods for the short-term, hourly, or daily report. To avoid accidental printing of the hourly or daily report manually, a safety feature has been included so that a manual print-out for the latter two reports requires the depression of both the selected report button as well as the short-term button. The dial at the left-hand top corner of the panel is for the selection of the short-term print-outs. By setting this dial at one of the positions of the switch, a short-term print out may be obtained for 5-, 6-, 10-, 12-, 15-, 20-, or 30-min intervals. The setting of this dial at the manual position eliminates the print-out of a short-term report. In this position of the dial, only daily and hourly reports will be printed out automatically on the output tape for all the stations. Selective print-out of data for any particular station is not possible.

The four individual pushbuttons in the center of the lower row of controls on the panel are used for the preparation and starting of the telecounting system. The start button will place the computer in action. The button on its right will allow the general reset of all the stations and addresses on the memory disk. Selective reset of any particular count for any station is accomplished by momentarily pushing the station reset button. A normally nonilluminated indicator on the top right-hand side of the panel lights up to indicate a power failure or the reduction of the AC supply voltage below an acceptable limit. In this latter case, a fail-safe circuit is actuated which inhibits the application of information to the disk. This eliminates the possibility of entering the wrong traffic count due to the malfunction of any part of the circuitry in the computer. To supplement the power failure indicator, an audible signal is also produced in the rack which can be repeated at any other remote location.

The unit below the display and control panel is the manual check-out panel (Fig. 9). The manual check-out panel contains 325 indicator lamps connected to the outputs of the different functional circuits to indicate their operational status. The indicators, by continuously showing the operating status of the circuits to which they are connected, provide for ease in servicing the computer equipment. In addition to indicating the

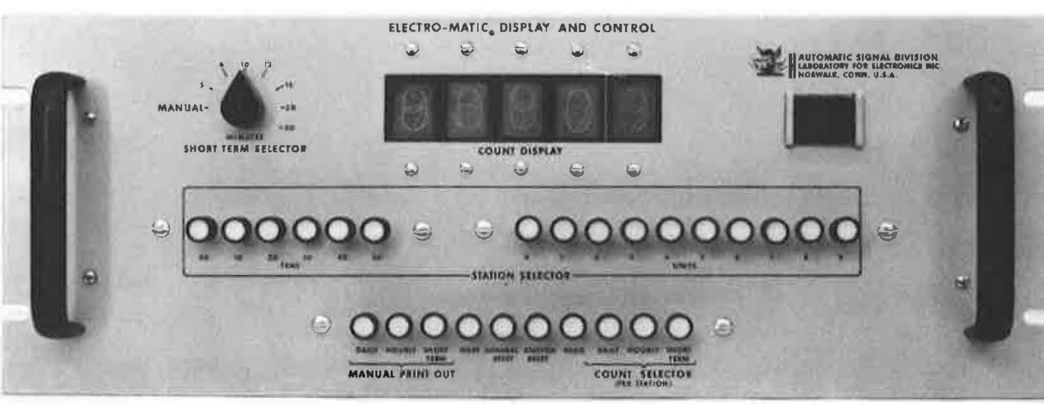


Figure 8. Display and control panel.

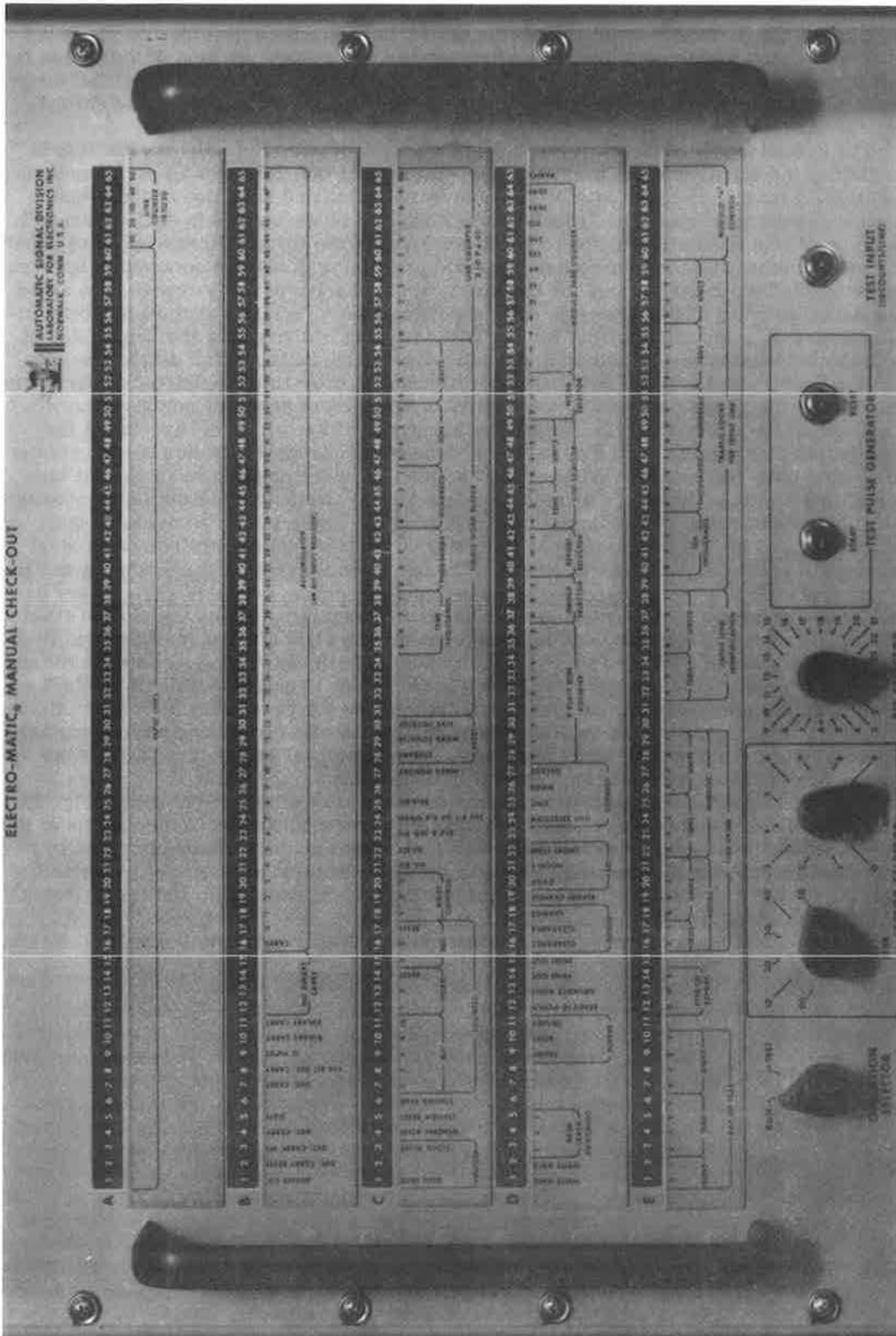


Figure 9. Manual check-out panel.

operative condition of the different cirucits of the computer, the indicator lamps also enable the entire system to be checked out by the injection of artificial signals into the computer. Checking of individual address locations on the memory disk may be effected by means of the controls located on the lower portion of the panel marked "sector selector" and "bit selector" as well as the "test pulse generator." These controls are inoperative unless the selector at the bottom of the left-hand rack is set to the test position.

The change of function of this panel from run to test is accomplished by the knob on the lower left side of the panel. In the test position, pressing the test input button on the right-hand side of the panel puts in ten counts on each input line. Thus, a check-out of the output tape will indicate whether the circuitry is performing properly with reference to entering the information on the data track, processing it, and writing it back on the memory track. A simulation pulse generator has been incorporated in the manual check-out portion of the computer which makes the computer go through its functions at a slow pace enabling the servicemen to observe any abnormal indication if present.

Figure 10 shows the tally paper tape punch which prepares the tape. The output tape, as mentioned earlier, will be used as the input to the majority of general purpose computers for processing of the data, or as the input to an electric typewriter for a numeric print-out of the reports. The output tape operates automatically at the end of the day and by the hour, on the hour, as well as at preselected short-term periods.

The last but most important part of the system is the Bernoulli disk (Figs. 11 and 12). The top portion of Figure 11 shows the rack of printed circuit boards related to the disk, and the lower portion has a switch on the left-hand side to start or stop the Bernoulli disk manually.

Figure 13 is a simplified flow diagram of the system. The detector pulses from the

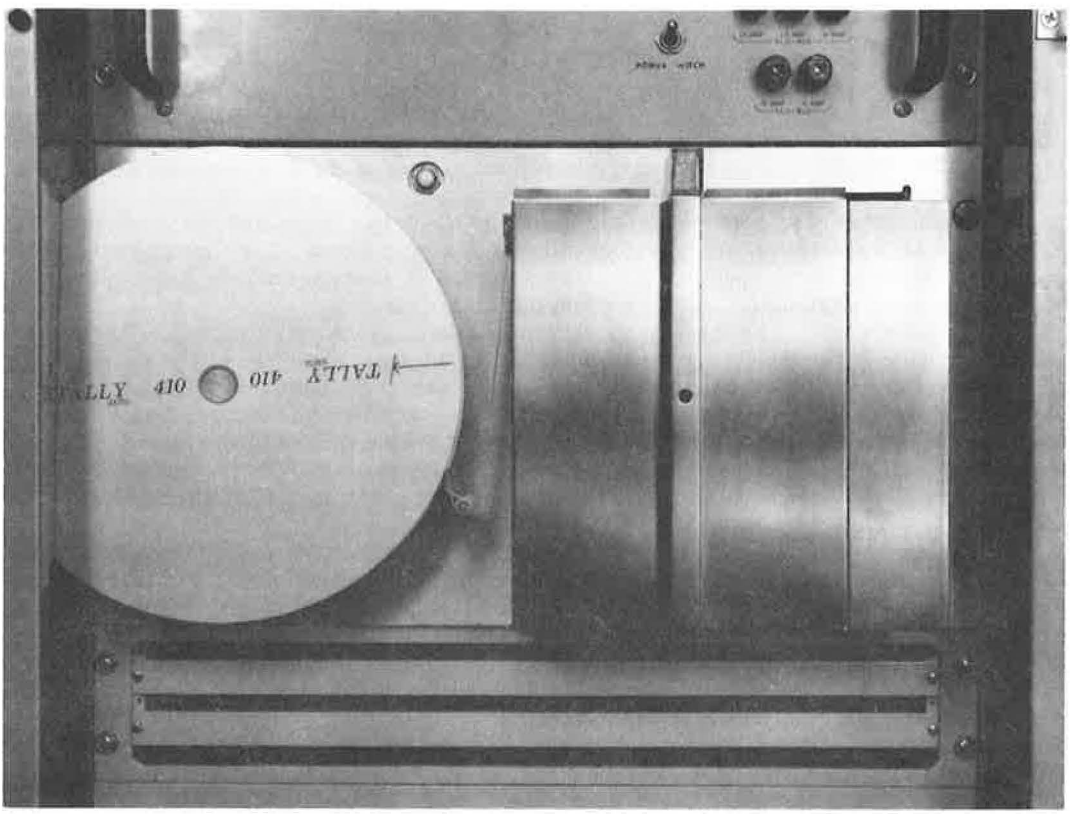


Figure 10. Tally paper tape punch.

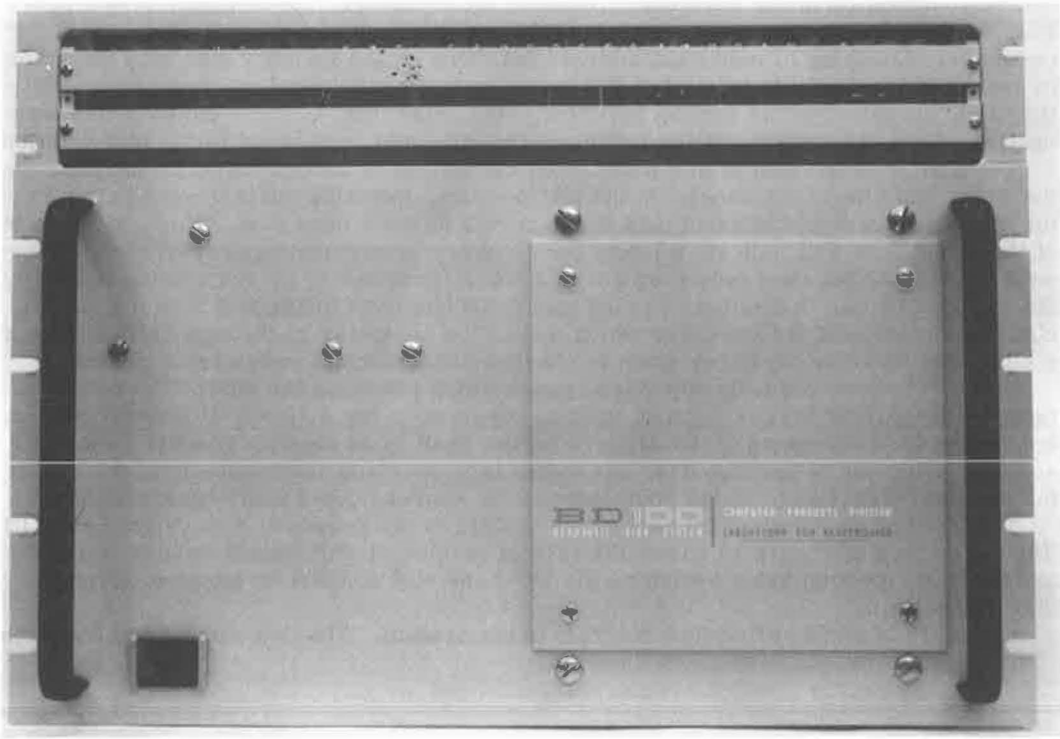


Figure 11. Memory disk panel and associated electronic circuitry.

different stations are fed into their respective temporary storage circuits. A line selector interrogates these storage circuits in succession to check if a traffic count has been registered in the temporary storage circuit.

The memory storage represented by the large block has three distinct storage cells for each input line—180 in all, corresponding to 60 input lines. The memory device could be compared to an endless chain with a series of storage buckets passing through a loading station designated as "Adder" on the diagram.

The memory device and the line selector operate in synchronism to allow the detector information from any line to be transferred to the buffer storage at the proper time so that it can be dumped in the corresponding memory cells (short-term storage cell, hourly storage cell, and daily storage cell) for that particular detector station. This transfer from buffer storage to memory storage is accomplished in the adder. The number of traffic counts stored in the temporary storage as well as the buffer storage can not possibly be more than one because the interrogation cycle lasts for only 50 millisec.

The memory storage loop goes through a control unit that, through commands received from the manual control at any time, or from the digital clock at preset intervals, extracts the information from the memory device and transfers it to the tape punch for a permanent record of the traffic count for each station on the paper tape. Following the transfer of the stored information from the memory to punched tape, a new counting cycle is started on the memory storage for that particular type of traffic report; i.e., short-term, hourly, or daily. On the other hand, if the read-out control unit receives a manual command for a visual read-out only, the updated traffic count for any selected detector station will appear as a numeric indication on the count display without resetting or destroying the updated count information on the memory storage device. As mentioned earlier in the text, a digital clock furnishes the print-out commands to the control unit for print-out at regular intervals and at the same time supplies the correct

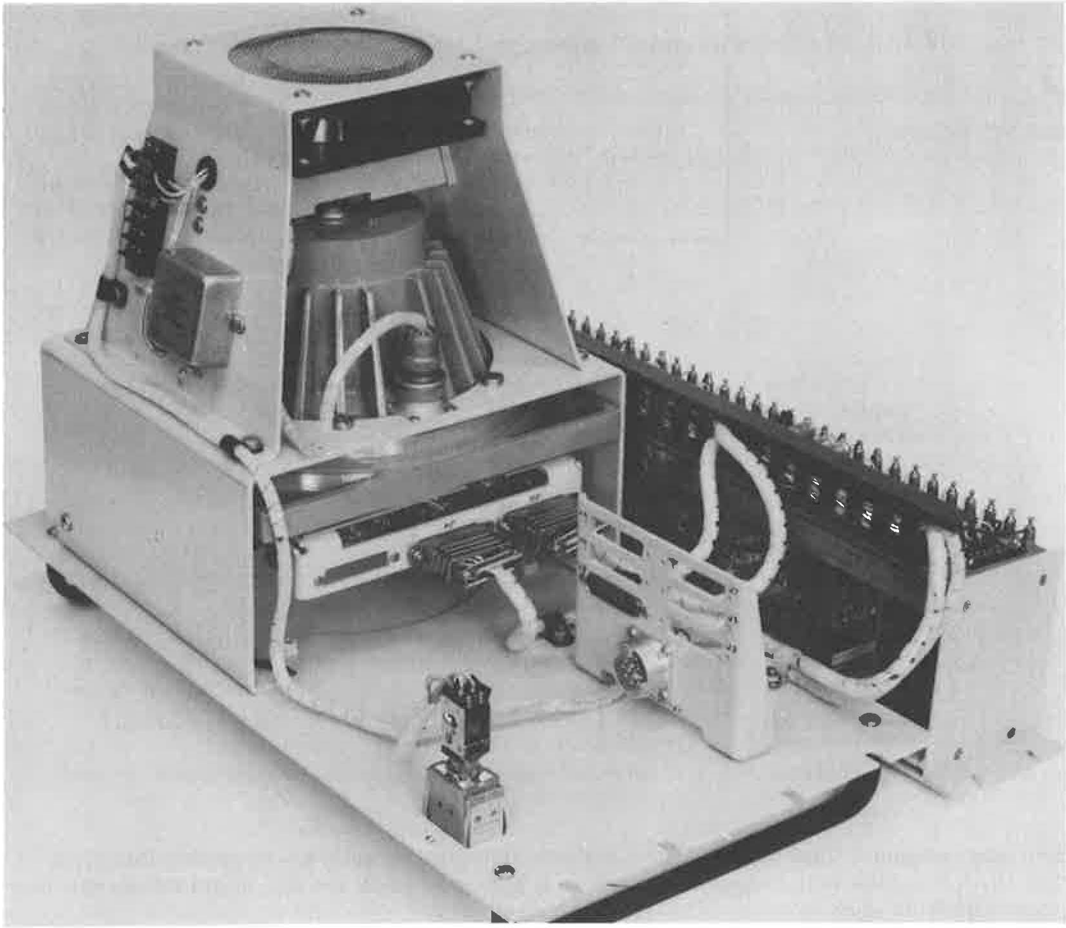


Figure 12. Rear view of memory disk panel and associated electronic circuitry.

date and time information to the paper punch for chronological identification of the report.

The preceding description summarizes the functional characteristics of the computer. The following are some of the advantages of the centralized traffic count system:

1. High-density resolution. The high-speed scanning and checking of information on the 60 input lines insures high resolution even in the heaviest traffic with a minimum possible headway. The sensing cycle being only 50 millisec, it is ten times faster than any possible rate of arrival of vehicles at the detection point.

2. Continuous data availability. Due to the fast read-out and printing of the transmitted data, there is no loss in count as received by the computer. Traffic counting is accomplished without any break in the processing, even during the printing operation.

3. Manual read-out. By selecting the station and pushing the appropriate read-out pushbutton the display of the updated traffic count for the short-term, hourly, or daily accumulated traffic count for that particular station can be displayed in numeric form on the display panel. This is a useful feature which insures the remote checking of any detector location at any time without affecting the print-out of the collected data on the tape.

4. Traffic counts on per-lane basis. The traffic counts in this telecount system are accumulated on a per-lane basis and automatically provide the traffic volume in vehicles per hour per lane. When a detector covers one lane only, the information is transmitted

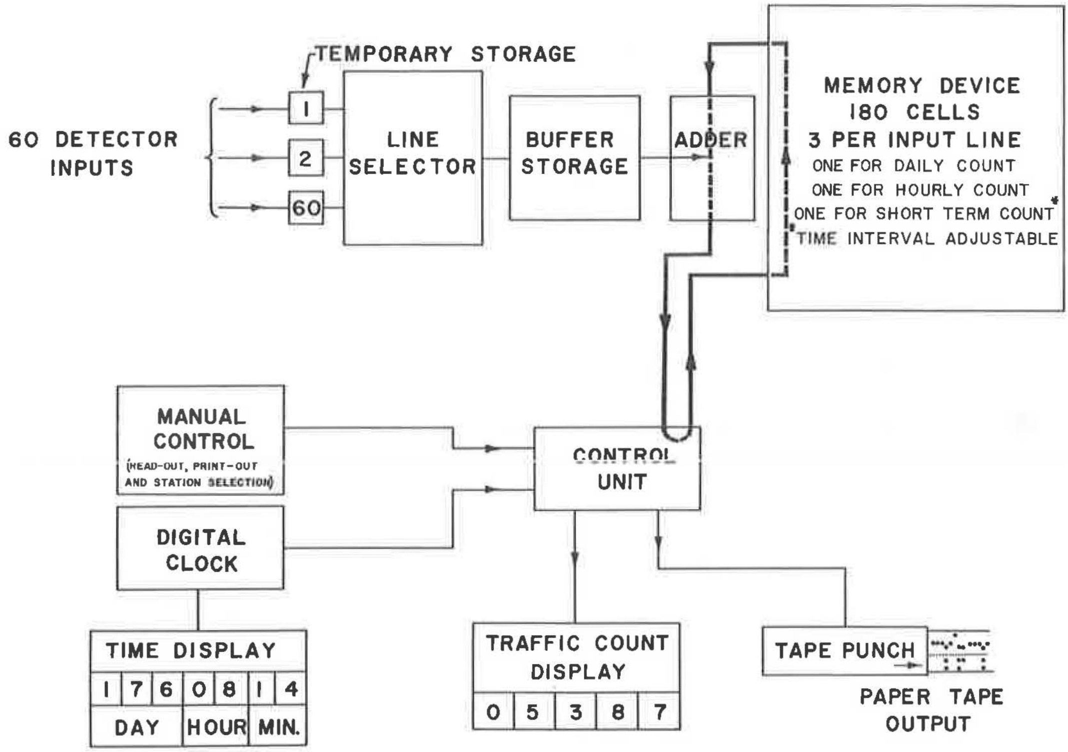


Figure 13. Functional block diagram of telecount system with 60 detector inputs.

over the telephone line as is. When a single detector is used to cover two lanes, a two-to-one scaler will reduce the count to a per-lane base and the information will be transmitted as such to the traffic-counting computer.

5. Ease of detection of detector failures. The detectors being used as sensors for the traffic counts are normally spread over a wide area. A visual check at the computer will clearly indicate if data are being received from any one of the 60 sensing stations. As a result, the presence of any traffic actuation at any counting station may be determined at a glance.

6. Manual start and reset. The digital clock, which is part of the system, can be set and started at the push of a button at any time. Also, at the push of a reset button, the traffic counts previously recorded in the memory storage can be erased and a new traffic counting cycle started.

7. No cards. The use of a punch tape output eliminates the need for individual cards for each report. In the majority of applications, the tape is directly fed into the general purpose computer, thus eliminating the possibility of mislaying or losing the cards.

8. Reduced high-speed computer time. It is common knowledge that high-speed general computers are quite expensive in hourly operational costs. If it were necessary continuously to feed the traffic-count data into a general purpose computer, an expensive piece of equipment which could have been used beneficially for some other purpose during this time, would be occupied. The purpose of this traffic-counting system is to gather the information on tape while the general purpose computer is free for use for other purposes. Thus, the latter computer is used only for a very short period of time for the complete processing of the collected data.

9. Reduced data processing. As compared with manual data processing, the tape output obtained by the paper punch reduces tremendously the manpower and time required to process the basic counts furnished by the detectors, by feeding the totalized

information into a general purpose computer. The general purpose computer will, with the data applied from the paper tape, perform any additional computation.

10. Computation errors eliminated. Because the traffic count is received and recorded without the intervention of any human element, including the processing of the punch tape, the final results are free from any possible human error.

11. Low communication costs. With the use of tone coding, the party line method of transmission can be used effectively and economically. This will decrease the cost of rental of telephone lines because up to 20 stations can be put on one party line. This is accomplished with the use of tone generators at the detector station, and decoding circuitry at the receiving end.

12. Modular design. The whole system is built on a modular design which gives it great flexibility. All of the basic circuits (i.e., the flip-flops, gates, multivibrators, etc.) are on plug-in types of printed circuit modules which are easily removable from the racks.

13. Transistorized circuitry. The computer is transistorized in its entirety except for the tally punch and the memory disk proper. This insures low power consumption and reduces the size of the computer. In addition, heat generation in the equipment is reduced tremendously.

14. Military design. Military design is a term quite loosely used and synonymous with the word reliability. The techniques used in the design and assembly methods, as well as the quality and grade of the components used, classify this unit as a highly reliable piece of commercial equipment.

15. Wide temperature range. The use of silicon transistors throughout the computer insures the reliable operation of the computer in the temperature ranges of from -20 to +170 F, without the use of forced air cooling.

16. Long life. Judicious selection of computer-grade components insures long operating life with a minimum of down time.

17. Low power consumption. The entire computer system has a current drain of only 6 amps at a nominal AC line voltage of 115 v.

18. Reduced field maintenance. Because all the equipment is centrally located field maintenance is reduced to the detection and transmitting equipment only.

19. Low mechanical wear. Because the digital computer, with the exception of the printed tape punch and the Bernoulli disk, is an all-electronic piece of equipment, there is practically no mechanical wear involved. The construction of the tally punch is such that millions of operations are required before the changing of any of the punches. A more detailed description of the Bernoulli disk follows at the end of this paper.

20. System check-out circuitry. The incorporation of a system check-out in the computer will be found invaluable in helping the serviceman to check the entire system.

21. System test circuits. This feature enables the operator to watch the operation of electronic circuitry. Unlike a mechanical system which would give an audible or visual indication of its operation, electronic solid-state circuitry operates without any outward indication of its status; therefore, indicator lamps are connected to the circuitry to provide a visual indication of its operation.

The Bernoulli disk used in this computer is a type of memory disk that, compared to other comparable memory equipment, has numerous advantages. It is a rotating, magnetic storage device using the Bernoulli principle to stabilize the flexible recording medium. The rotating disk pumps air between the disk and head plate. This flow is controlled so that the aerodynamic forces of air and the dynamic and elastic forces on the disk resolve in a stable equilibrium. The flow of air assures a close and controlled separation between the disk and the head plate and prevents contact between them. The following are some of the considerations in the design of the disk.

1. Simplicity of design which yields inherent reliability and long life.
2. Closely controlled separation permits reliable, high density recording at a low cost per bit.
3. High storage capacity with small physical dimensions.
4. No head adjustment required during installation. It has separate read and write heads.

5. Preloaded, sealed bearings require no maintenance.
6. Units are lightweight and compact.
7. The unit is hermetically sealed.
8. Proper selection and matching of materials provide wide operating temperature range.
9. Stabilizing forces are large in comparison with the mass forces acting on the light, thin flexible disk, providing a rotating device insensitive to external shock and vibration.
10. Magnetic drive coupling, operating through a stainless steel diaphragm, isolates the disk from the mass of the motor.
11. Low disk mass minimizes gyroscopic effect.
12. Low mass results in negligible disk bearing loads.

Efforts have been made to describe the telecount system as simply as possible without going into any technical details as far as the electronic or logic circuitry is concerned. Furthermore, coverage has been limited to a description of the computer as shown in Figure 3.

As mentioned previously, application of the system in study areas of various sizes will possibly require expansion of the computer to accommodate more input lines. Other types of output, as well as other output formats (such as incremental magnetic tape), are also obtainable.

A preliminary analysis of the economies associated with the use of this system vs the present manual method of data collection and processing indicates a definite saving in manpower and time with the additional benefit of having the data available for immediate processing.

The built-in capability of the computer to give short-term traffic counts down to 5-min intervals is a great asset for spot studies of troubled locations.

Even though the telecount system has been designed primarily for the purpose of traffic counting, the instantaneous information displayed by the computer could conceivably be used by agencies such as traffic departments of States, counties, or municipalities for surveillance purposes.

ACKNOWLEDGMENTS

The authors express their appreciation to Howard S. Ives, Connecticut State Highway Commissioner, for permission to locate the computer in the State highway department building and make use of the present ATR stations as input sources to the computer for this field test. Special appreciation is due to David S. Johnson, Jr., Israel Resnikoff, and Israel Zevin of the Planning, Traffic and Design Division, Connecticut State Highway Department, for their cooperation during this field test in supplying traffic data previously collected for comparison purposes and help in the installation at the detector locations.

Appreciation is also expressed to the sales and technical staff of the Southern New England Telephone Company for their efforts and cooperation in supplying the network which proved the feasibility of the system as a whole.

A word of thanks is due to Mr. Mulvany of Friden for providing a Flexowriter for use during this test, and to the members of the Development Laboratory of Automatic Signal, sincere thanks for their participation in this project from the time of conception to date of complete installation for the long hours they had to put in to make this project a success.

Automatic Traffic Counters

C. J. CRAWFORD and A. E. RUSSELL, North Dakota State Highway Department; and
ROY SHIMER, U. S. Bureau of Public Roads

This paper discusses the design of a new type of traffic counter and interpreter presently being used in North Dakota. Basically, the method evolves around the principle of moving a tape a certain distance for each vehicle passing the counter. The interpreter reads this tape, converts the hourly tape travel into number of vehicles, and punches these hourly totals in the proper field on a tabulating machine punch card along with their identification data. This equipment eliminates all the manual operations previously necessary in the analysis of the field tapes, punching of the cards, and related activities in the office.

• TRAFFIC STUDIES have been one of the principal activities of the State Highway Planning Survey since its beginning in the mid-1930's. Many items of information are gathered in a traffic study, but one of the most important is the information gathered by the fixed-type automatic traffic counters.

In North Dakota, five IBM model 3900 traffic counters were installed in 1936. In succeeding years, additional counters were installed and by 1961 there were 34 fixed-type automatic traffic counters operating in the State. These counters printed the cumulative hourly totals on a tape and the hour volume was obtained by manually subtracting the preceding cumulative total from the succeeding cumulative total. These hourly totals were then listed on coding sheets, punched in tabulating cards, and verified before they were available for mechanical analysis

Over the years these traffic counters have been remodeled and improved, but regardless of this, certain critical parts of the equipment are original parts. Because of this, the equipment was becoming more susceptible to failure, repair parts were difficult to obtain, and their cost was often hard to justify. Replacement of this equipment as well as obtaining additional equipment was necessary, but no equipment was available that met the State's requirements.

OBJECTIVES OF EQUIPMENT DEVELOPMENT

The State's requirements, as set up, covered existing deficiencies in the operating equipment as well as improvements desired. The following were major requirements:

1. All manual operations now necessary for determining the hourly volumes had to be eliminated.
2. Traffic counts and the time interval had to be recorded on a medium that could be readily interpreted.
3. The interpreter had to read the medium quickly and accurately, and punch the hourly volumes and other identification data directly on tabulating cards.
4. The recorder had to give continuous and accurate operation regardless of power-line outage for a reasonable period.
5. The recording equipment had to be economical to construct and simple to maintain.
6. Changes in temperature, particularly low temperatures, should not affect the recording unit.
7. Repair parts had to be readily available.

Paper sponsored by Committee on Electronic Research in the Highway Field.

With these requirements as a guide, it was decided to attempt to design and determine the feasibility of equipment to meet the needs of Items 1 and 3, first. This unit is called herein the interpreter. When it became apparent that no unusual difficulties would be encountered in the interpreter, work on the traffic counter was begun and development of both units was carried on simultaneously.

TRAFFIC COUNTER

Synopsis of Operation

Figure 1 shows an automatic traffic counter station on Interstate 94, and Figure 2 is a close-up of the counter. Figure 3 is an inside view of one of the counters, showing the arrangement in the counter case of the recorder, power supply, amplifier, and delay circuit. The smaller case holds the 12-v storage battery.

With the successful development of this new counter, the number of locations has been increased from 34 to 50, and it is expected that even more will be installed as the urban studies are expanded and additional interstate mileage is completed.

Every traffic counter is inspected twice each month, at the beginning of the month when the tapes are removed and again about the middle of the month. All maintenance is carried on from the central office. Equipment in need of testing or major maintenance is replaced in the field with spare equipment carried by the maintenance crew.

The tapes, as removed from the traffic counter, are forwarded to the central office shortly after the first of the month. The hour of the tape removal from the field recorder is marked on each tape. This hour of removal is the total hours cumulated since zero hours on the first day of the preceding month. The cumulative time, in hours, for the current month is then reset in the counter.

Features of Design

The traffic counter unit described in this paper includes only those items of new design and does not include any item previously in use. The equipment shown in Figure 4 is a front view of the "recorder." Figure 5 is a rear view of this unit. The purpose of the recorder is mainly tape and time control. Figure 6 shows the power supply unit. These are the only parts of the traffic counter discussed.

Assuming that the traffic counter is ready to operate, it is only necessary to set the time. To do this, it is necessary to loosen the lock screw at top of H (Fig. 4) and move

Figure 1. Automatic traffic counter station, Interstate 94.

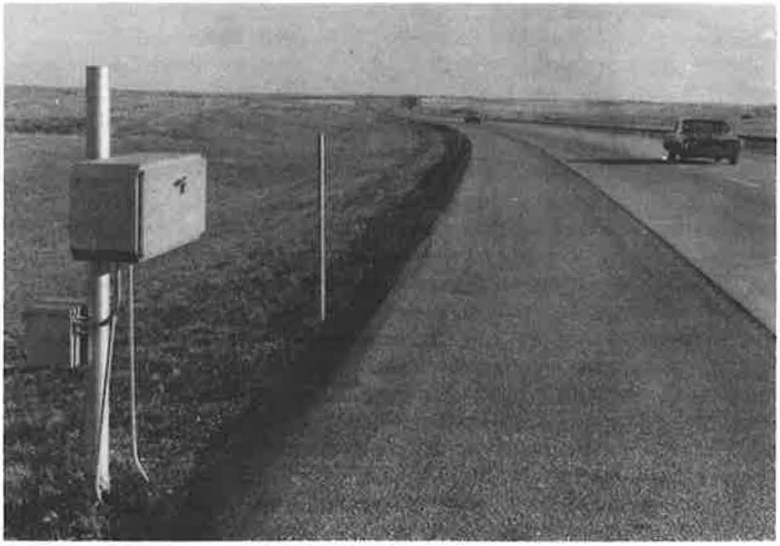


Figure 2. Close-up of counter.

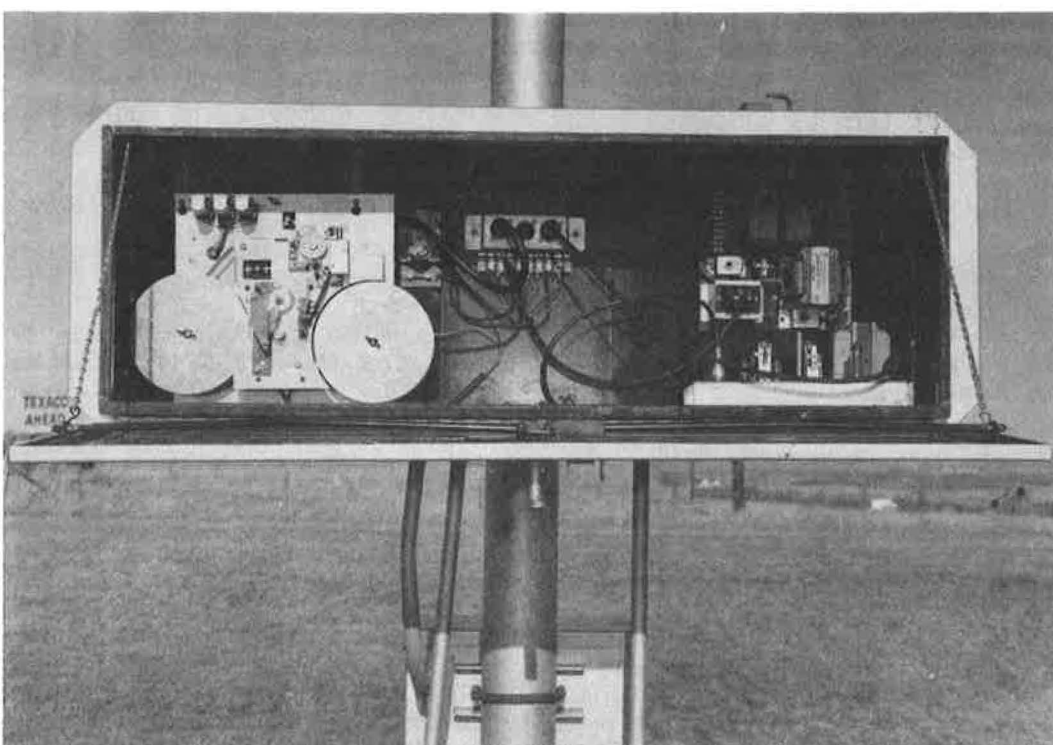


Figure 3. Inside of counter.

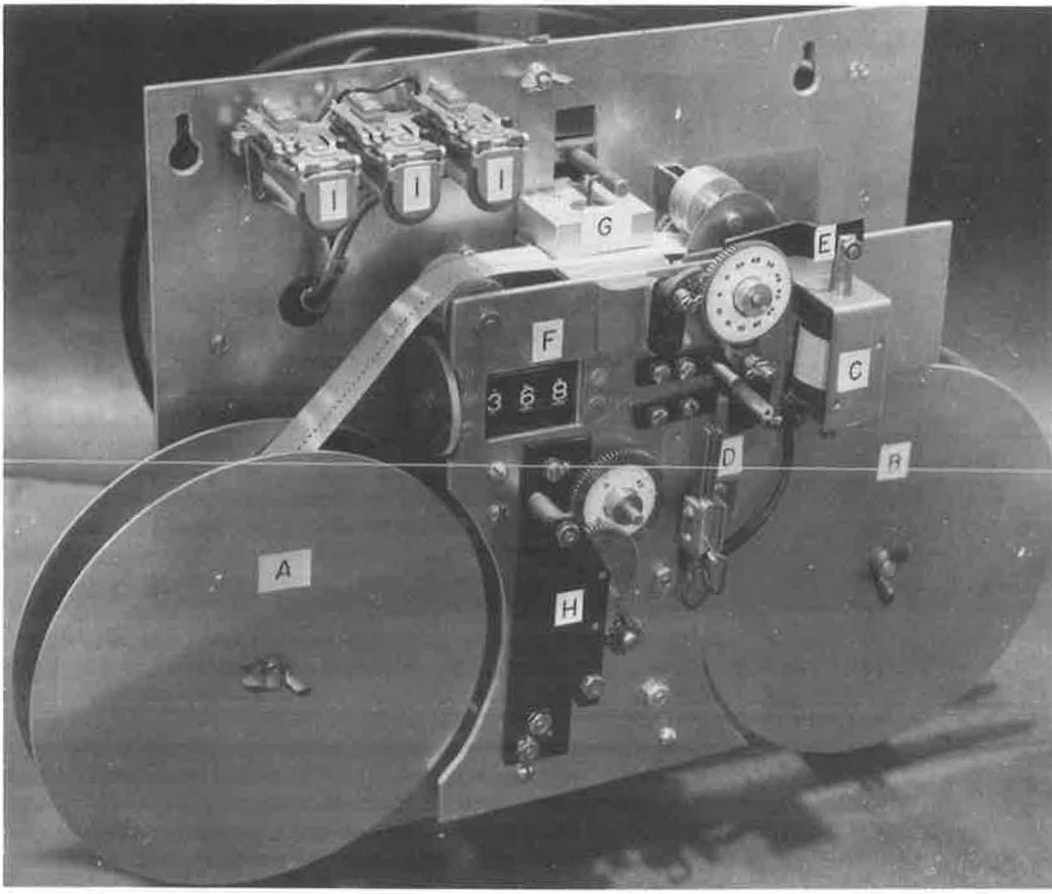


Figure 4. Recorder, front view: tape supply reel (A); tape takeup reel (B); counter solenoid (C); counter cutout relay contact (D); tape advance operating arm (E); hour indicator (F); hour hole punch and die (G); timing gear train (H); cutout relays (I).

the assembly to disengage the timing gear train, then set the hour indicator F (Fig. 4) at the total hours cumulated in the current month. The minute wheel is set to show the proper minute and the gear chain re-engaged and locked. The counter is now started by switching it on the 110-v power and the storage battery. The timing motor operates from the 110-v line, and the rest of the counter operates from a 12-v storage battery.

A vehicle passing the station generates a voltage in the road coil, which is amplified and activates solenoid C (Fig. 4). This in turn moves the tape $\frac{1}{30}$ in. The movement of the tape must be positive and exact. To insure this, the mechanism identified by X and Y (Fig. 7) was developed. The extrusions on the tape driving wheel fit in the holes of the tape and the groove of the riding wheel, thus insuring positive and accurate tape movement for each passing vehicle.

If no traffic were to pass the stations some hour, the tape would not move and the hour punch would repunch the previous hour hole and the time sequence indicated by the hour holes would be lost. To avoid this, a cam (R, Fig. 5) causes the counter to add four extra counts each hour and this moves the tape enough so that the hour holes are separate and distinct and the time sequence is not lost. Provision has been made in the interpreter operation to eliminate these four extra counts.

The hour punch solenoid (P, Fig. 5) is actuated by the hour snapswitch which is controlled by the timing motor, (K, Fig. 5). The timing motor also controls, through the timing gear train (H, Fig. 4), the cumulative hour indicator (F, Fig. 4), and the minute indicator.

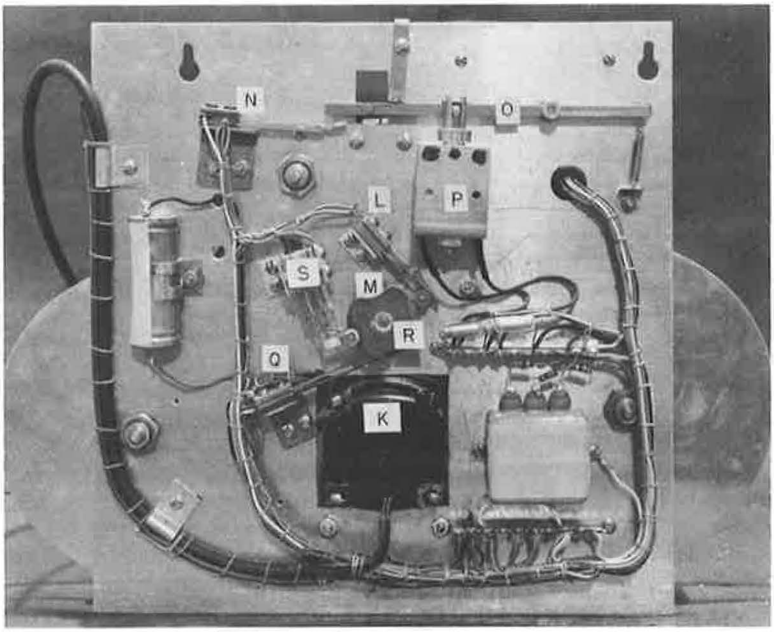


Figure 5. Recorder, rear view: timing motor (K); hour snapswitch (L); hour cam (M); hour hole punch relay cutout contact (N); hour hole punch operating arm (O); hour hole punch solenoid (P); hour snapswitch cutout contact (Q); extra count cam (R); extra count and counter relay cutout snapswitch (S).

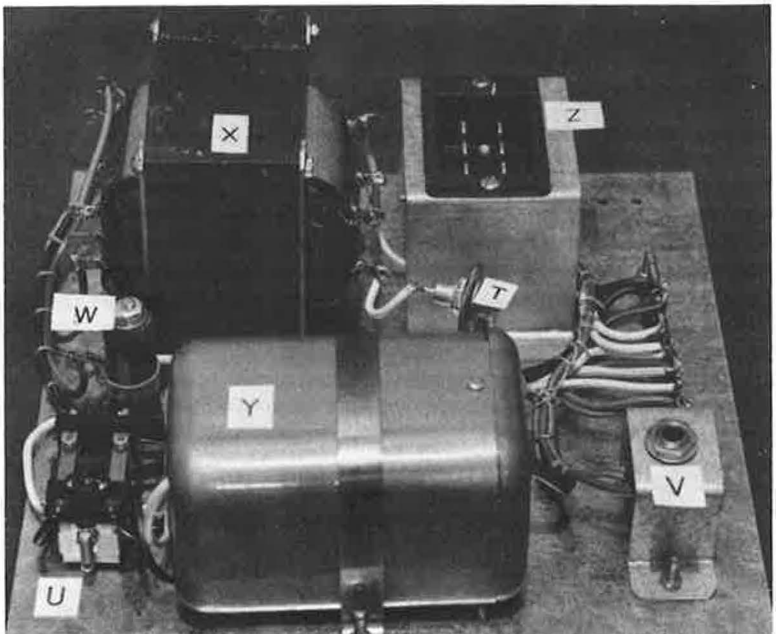


Figure 6. Power supply unit: silicon rectifier (T); AC relay (U); charging rate meter jack (V); charging rate adjusting resistor (W); rectifier transformer (X); inverter (Y); connection plug (Z).

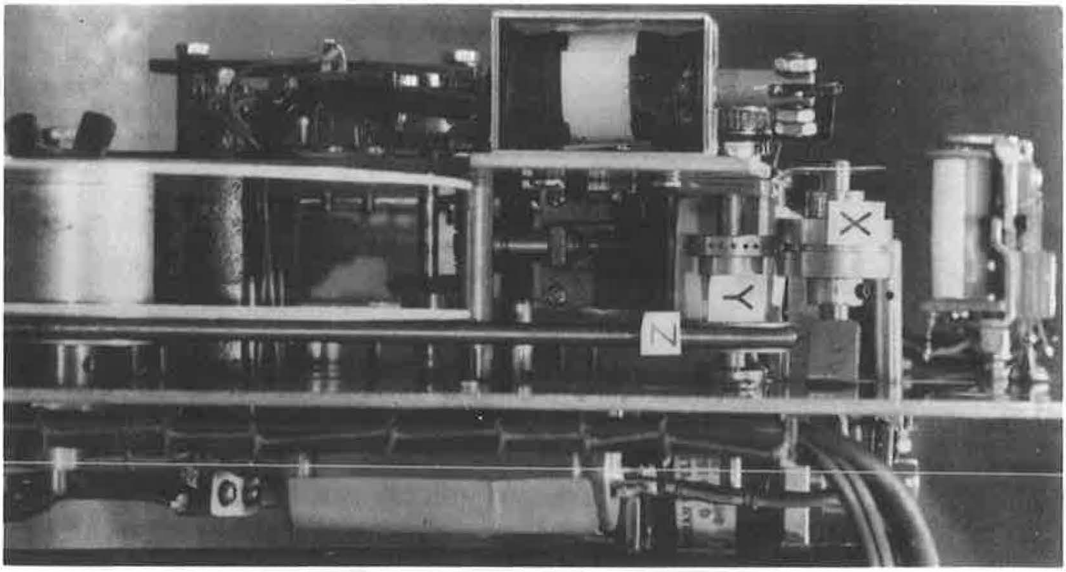


Figure 7. Tape-moving mechanism: tape riding wheel (X); tape drive wheel (Y); takeup reel drive spring (Z).

The power supply unit is shown in Figure 6. As previously stated, all power for the counter is obtained from a 12-v storage battery except for the timing motor which operates from the 110-v power line. If the line power fails, the AC relay (U, Fig. 6) drops out and connects the battery to the timing motor through the inverter (Y, Fig. 6), and, if the power is not restored, the counter will continue to function for about 30 hours. If, in the meantime, power is restored, the AC relay will pick up, again placing the timing motor on the 110-v line. The battery will begin recharging and no interruption in counter service will have occurred.

Figure 8 shows the relationship of the main components of the traffic counter.

INTERPRETER

Synopsis of Operation

The interpreter is shown in Figure 9. There are two units, A and B. Although this is true mechanically, they are connected electrically and together comprise the interpreter.

The purpose of the interpreter is to read the tape that has been produced by the field

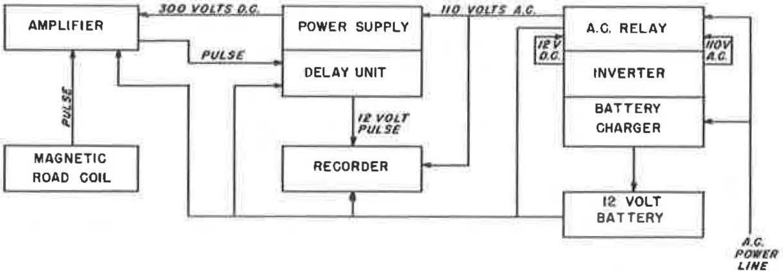


Figure 8. Relationship of main components of traffic counter.

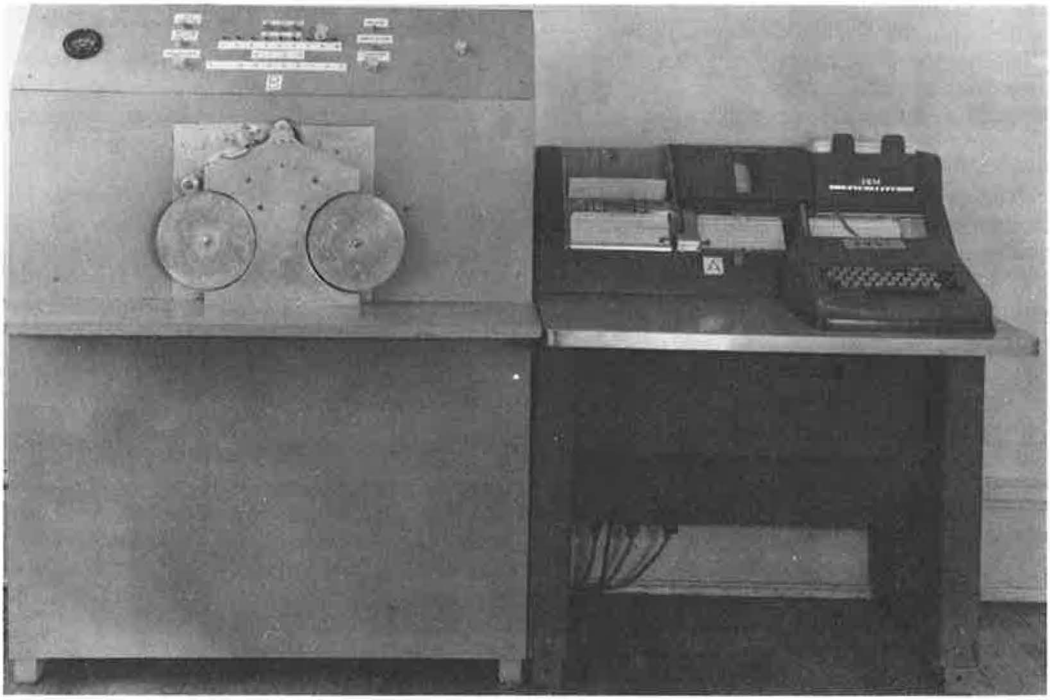


Figure 9. Interpreter.

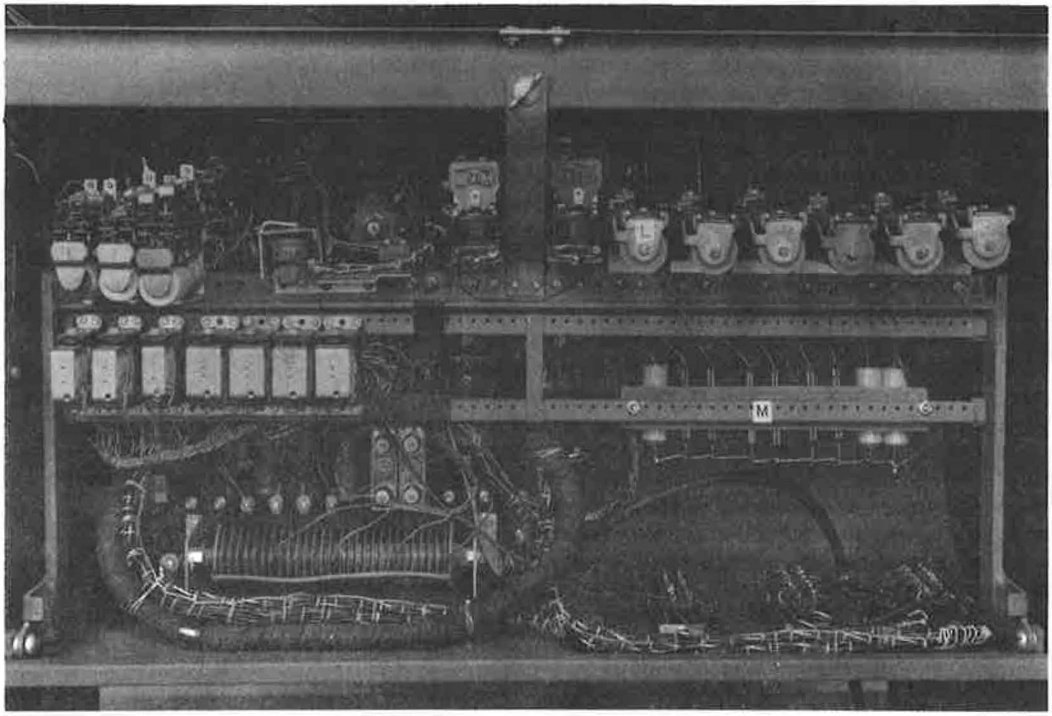


Figure 10. Rear view, Unit A (Fig. 9): program relay bank suppressor (L); spark suppressor condensers (M).

traffic counter and make a proper record of the data. The equipment that was modified or designed to do this is shown in Figure 9. Unit A in this figure is an IBM punch machine that has been modified, as explained later. Unit B is a specifically designed mechanism that reads the tape and stores the data until such time sequence is arrived at that the data are ready to be punched in the tabulating card. At that time, Unit B transmits the data, in proper sequence, to Unit A which punches the data as received, in the proper field on an IBM punch card.

The interpretation of the hourly volume data on the tape and the translation of these data to punch cards are accomplished much more accurately and rapidly than by the previous manual operation.

Salient Features of Design

It was the desire of the State to maintain as simplified a design as possible, and yet one that would produce the desired results. It is likely that through use and experience the mechanism can be further simplified. Several additional figures show portions of Units A and B in Figure 9.

Figure 10 is a rear view of Unit A (Fig. 9), which shows the added relay bank and wiring. This relay bank consists of three relays for the traffic volume, two for the date, and one each for date advance, control, reset, and control of the clutch solenoid. These additions in no way affect the original purpose of the equipment and it may be used as a manual punch machine at any time desired.

Figure 11 shows the tape reading unit and control panel. This is a close-up of Unit B (Fig. 9). The control panel has 14 indicator lights for the date, 9 jacks for selecting the starting date, 3 toggle switches for the number of days in a particular month, 2 momentary push buttons for manual reset of the stepping relays, and toggle switches for starting and controlling the photo cell amplifier and counting circuits.

Figure 12 is a rear view of the tape reading unit appearing in Figure 11.

As previously stated, the traffic counter tape is picked up some time after the first of the month. When it is picked up the station's number and total cumulated hours, as

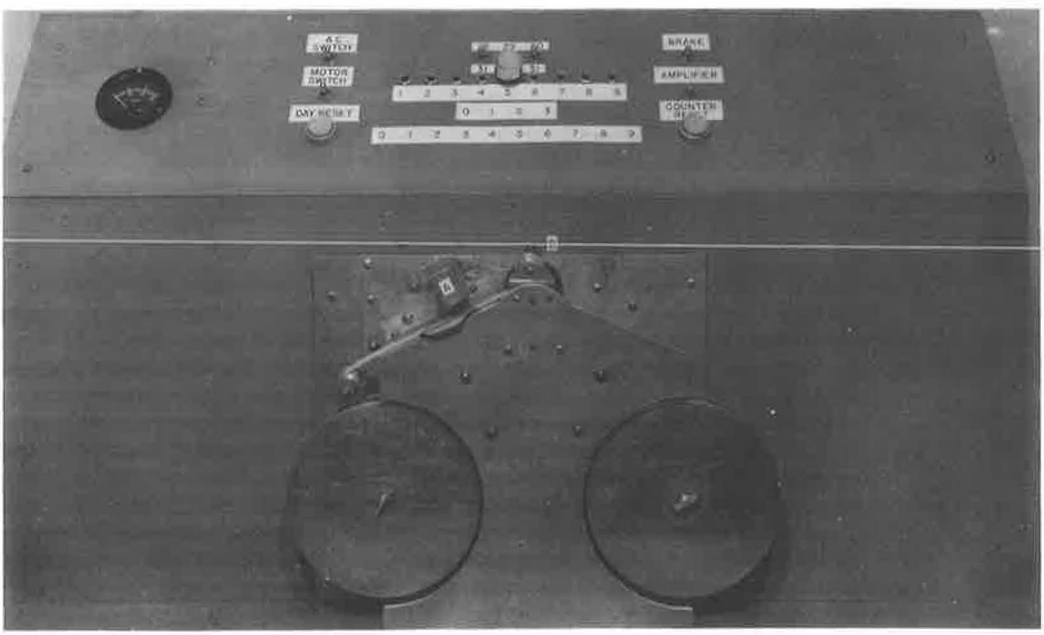


Figure 11. Tape reading unit and control panel: photo cell light source (A); tape transport mechanism (B).

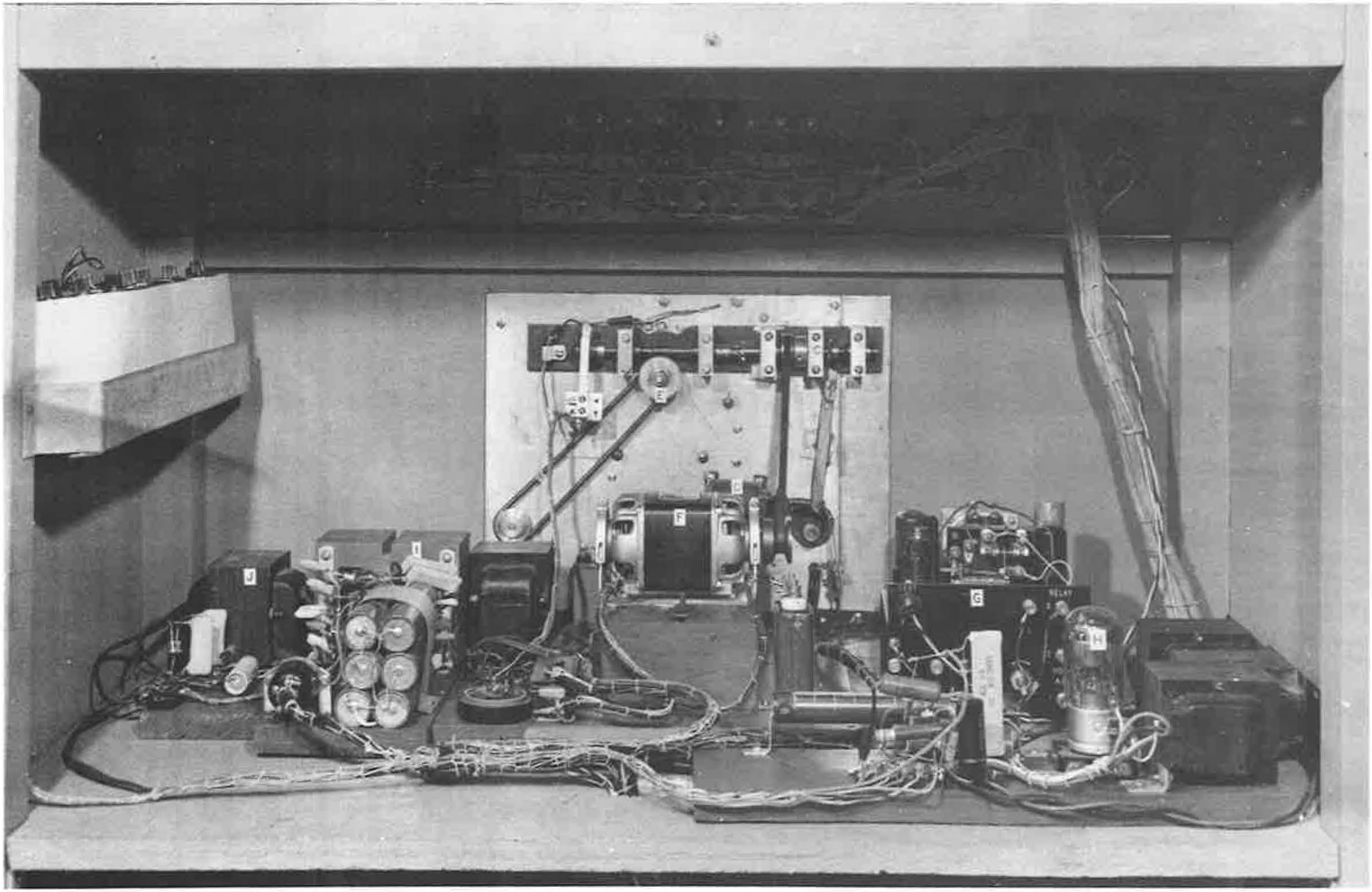


Figure 12. Rear view, tape reading unit: tape drive mechanism (E); drive motors (F); photo cell amplifier (G); stepping relay electronic switch (H); stepping relay power supply (I); program relay power supply (J).

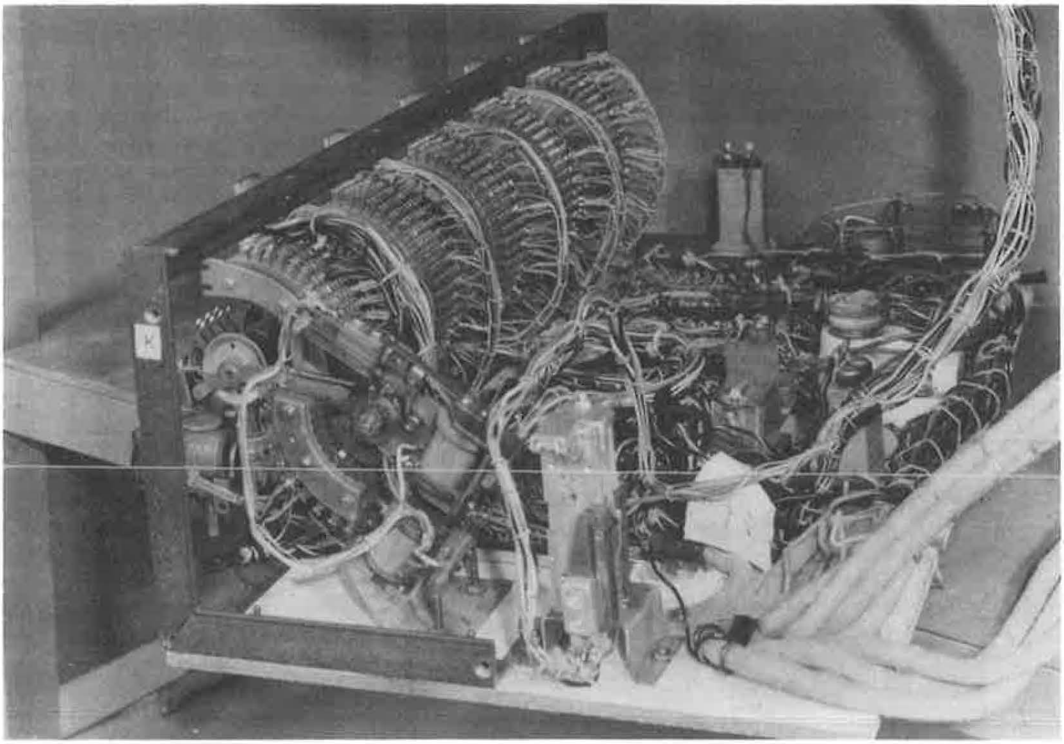


Figure 13. Stepping relays: rear view, stepping relay bank (K).

shown on the hour counter, are marked on the tape. From this information on the tape the interpreter operator can set up the equipment through the control panel (Fig. 11) to match this last recorded hour. The tape is then fed into the interpreter beginning with this last recorded hour or backwards. Doing this eliminates the need of rewinding or matching the previous month's tape.

The tape is fed through the interpreter by the same type of equipment as controlled its movement in the traffic counter. Because each vehicle passing the traffic counter caused the tape to be moved $^1/_{30}$ in., the interpreter reading head must interpret each tape movement of this amount as a vehicle and give a signal that can be recorded. This

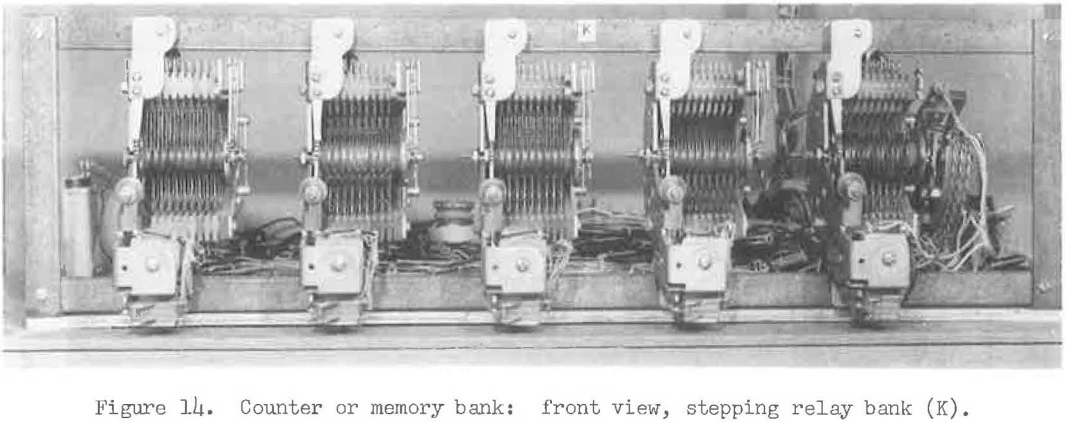


Figure 14. Counter or memory bank: front view, stepping relay bank (K).

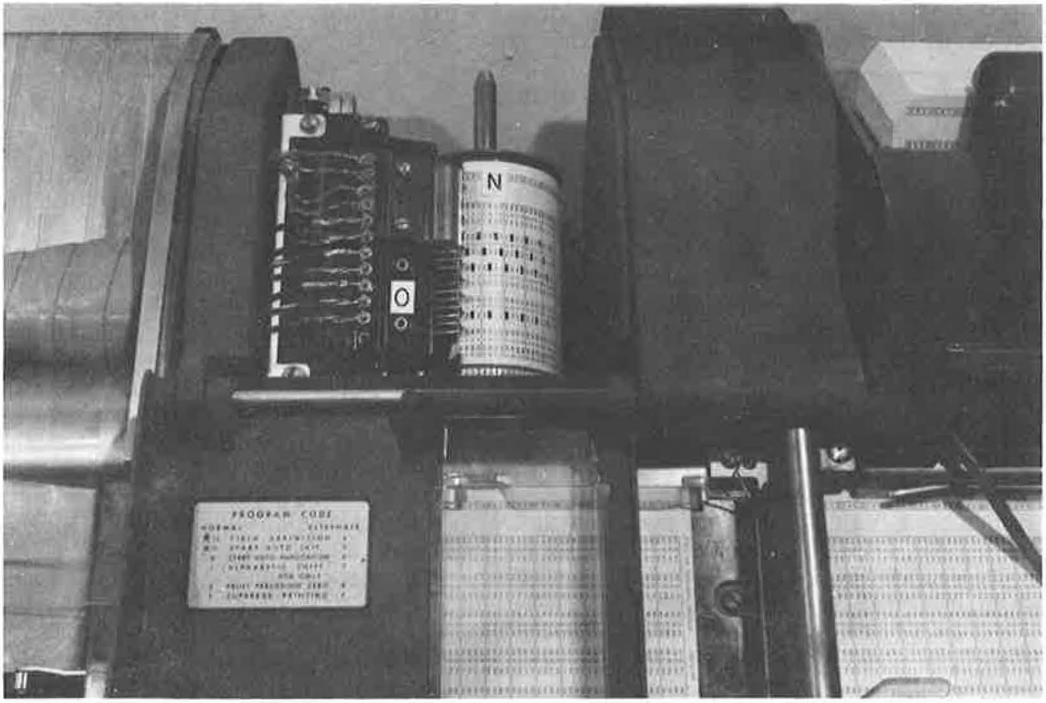


Figure 15. IBM card punch: program card (N); program contact assembly (O).

is done by the equipment shown in Figure 12. The signal is an electrical impulse that is transmitted to the stepping relays (Fig. 13), which advance one unit for each impulse. Each unit of advance of the stepping relays is therefore the equivalent of a vehicle passing the station.

As previously stated, four counts were induced to separate the hour holes at zero traffic and they must now be eliminated. This is done by shunting the reading impulses to a special stepping relay (Fig. 13) that is not a part of the memory bank. When this relay has received four impulses, it removes itself from the circuit and the balance of the impulses for that hour go to the stepping relays that compose the counter or memory bank (Fig. 14).

This summation of impulses continues in these stepping relays until the next hour hole in the tape intersects the photo cell light. This energizes a circuit that stops the tape.

These stepping relays are wired to the 10-punch interposer magnets in the IBM card punch, the time and sequence of punching is controlled by the program card (Fig. 15) and power is supplied through the relay bank (Fig. 10).

When the program card arrives at the last column in the field, a relay is energized that closes the stepping relay reset circuit. This relay holds until the stepping relays have all returned to zero. When in this position a series circuit is energized which closes a relay to de-energize the clutch solenoid. The tape then starts moving again and the cycle is repeated.

There is one tabulating card for each day. The first 72 holes are for the hour counts. This allocates three spaces for each volume and will allow for 999 vehicles. In North Dakota there are only a few counter locations where the hour volume ever exceeds this amount and then only in rare instances. These instances are readily recognized by the interpreter operator and are handled manually. Volumes requiring four card spaces could easily be handled by using two cards for each day instead of one. The remaining columns are used to show station number, day, month, and year. After the hour counts for one day have been punched, the date is punched on the card through

stepping relays controlled by the program card. The balance of the identification is punched by duplication from the previous card.

ANALYSIS

Planned Revisions

At the present time, the State has no planned revisions for the traffic counter. There may be some minor mechanical changes if better parts are found at a reasonable price. As an example, the tape punch is not giving completely satisfactory service in all instances. The failures to date have been of little significance, but they have occurred.

The counters have all been built in the Planning Survey shop, with relatively inexperienced help, but with technically competent supervision and it was expected that certain construction errors would occur that would not be found until after installation. So far, comparatively few have been found.

Some changes in the interpreter are planned. Most are of little importance. It is recognized that the stepping relays have certain limitations. First, they are relatively slow, as they will only cumulate about 19 units or vehicles per second. They are also subject to excessive wear. To overcome these disadvantages, an electric counting circuit has been built which has a speed about five times greater than does the stepping relays. This counting circuit was used in other North Dakota equipment during the summer of 1962 and has been very satisfactory. It is expected that this circuit will be installed in the interpreter shortly.

The speed of this circuit is much greater than is that of the clutch and brake assembly and possibly that of other parts. Improvement of these items must be made if the benefits of the electric counting circuit are to be realized. It is the intention of the State to continually up-grade the equipment.

Advantages and Disadvantages

This equipment has many direct advantages. It has met all the requirements previously set out in this report and they were all advantages. This applies to both the traffic counter and the interpreter. These advantages were nearly all mechanical in nature. Also of great value are the more complete and accurate data that are available at a much earlier date. There is also a considerable savings in salaries previously paid for work now done by the equipment.

It is the opinion of the State that this equipment has its greatest advantage over the previously used method when the ADT does not exceed 5,000 vehicles per day. When the ADT approaches 10,000, it appears that the original advantage has about been eliminated. If the present efforts to increase the speed of the interpreter are successful, then the comparative ADT just referred to will be materially increased.

There are also disadvantages. The disadvantages, however, generally center around personnel. This equipment requires greater skills on the part of the maintenance and operating personnel than did the equipment previously used.

SUMMARY

1. This paper describes a new method of counting traffic with automatic traffic counters and mechanical interpretation of that record.
2. This method is essentially a linear measurement procedure.
3. Further refinements that will improve the service of the equipment are being developed.
4. This method provides much greater accuracy in the data obtained from automatic traffic counters at a much earlier date.
5. This method has produced savings in operations that are now estimated at more than $100 per year per field counter.

Television Equipment for Traffic Surveillance

CHARLES L. RICHARD and KEITH BUSHNELL, respectively, Electrical Engineer and Systems Engineer, Michigan State Highway Department

This project consists of the establishment of a comprehensive system of surveillance and control on an urban freeway. The purposes of the project are to evaluate the use of surveillance, traffic control, and sensing equipment; to investigate the characteristics of the freeway traffic flow that may be determined and treated by such equipment; to improve freeway traffic operation and safety by these means, as well as to conduct basic research into freeway operations by making use of this specialized equipment. For the first time, it has become possible to assemble the specialized equipment required to carry on a project of this scope.

•CLOSED-CIRCUIT television has become an efficient tool for aiding in control of urban freeway traffic. Television cameras properly located can provide an observer with continuous visual information of a large area of freeway. On the John C. Lodge Freeway, 14 television cameras are spaced approximately ¼ mi apart so that a continuous 3.2-mi area of the freeway is under observation (Fig. 1). From one control point, it is possible to observe traffic movements, study driver behavior, determine the scope of an accident, direct rescue activities, operate traffic control devices, and visually assess the results of vehicle-sensing equipment in the area.

Without this television system, it would be difficult to develop, install, and operate a lane and speed control system. Twenty months of operation on this project have proved that closed-circuit television has "arrived" as a valuable tool for the traffic engineer.

Freeway surveillance proves to be one of the severest requirements placed on closed-circuit television. Tunnels, bridges, and airports have been using closed-circuit television, but usable pictures were not being obtained under existing low light levels. Because a major part of urban traffic problems occurs at dusk or after dark, especially in the wintertime, the less expensive vidicon-type television camera did not seem too practical. A recent report written for the City of Chicago stated that the necessity for a picture after dark would require the use of the more expensive image orthicon (Studio) type of camera.

Probably the major breakthrough has been the rapid advance in the development of the vidicon type pickup tube. Large, extensive projects by the military have caused a boom in the development of small closed-circuit television cameras, using small vidicon tubes.

The major problem in the planning of any closed-circuit television is the selection of the proper equipment which will meet the requirements of the application. The engineer has available a wide range of equipment which varies in function, performance, quality, size, and cost. Existing equipment capabilities must be fitted to meet certain performance criteria which will produce an acceptable video picture in a given situation. The basic closed-circuit television system consists of cameras, monitors, and a transmission system.

The application of these system characteristics and accessories including limitations and advantages as experienced on this project is discussed in detail.

Paper sponsored by Committee on Electronic Research in the Highway Field.

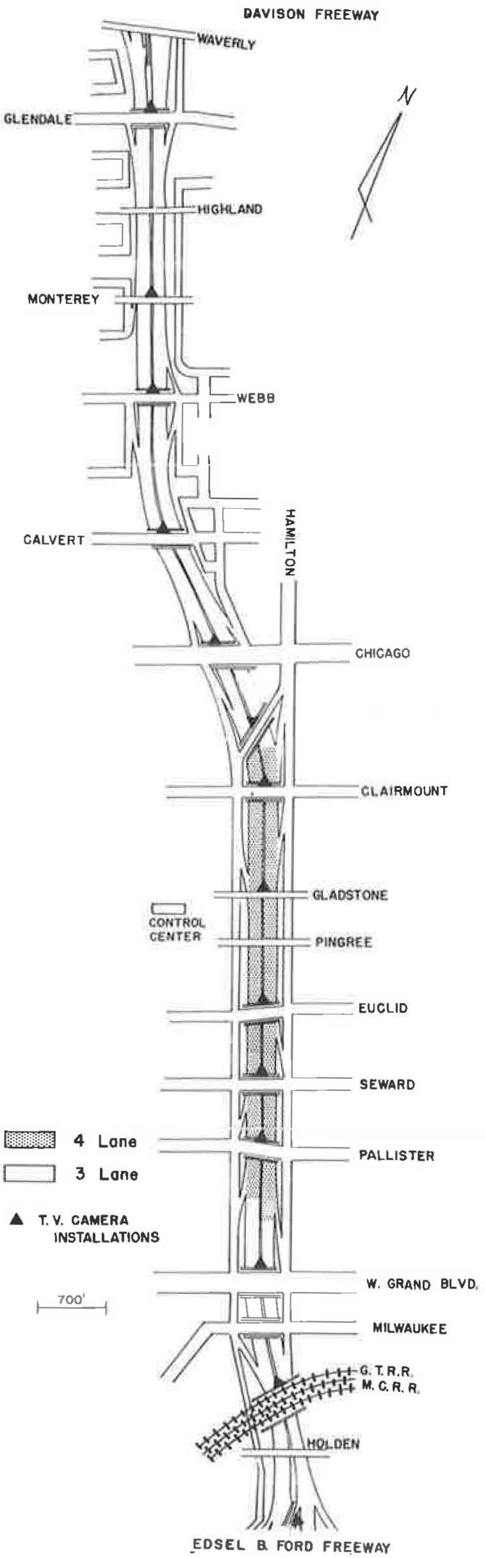


Figure 1. Freeway study area plan.

CAMERA CHARACTERISTICS

Vidicon Tubes

One of the first and most important decisions which has to be reached in planning the closed-circuit television system on a freeway is the selection of the proper camera pickup tube. In the present state of the art, this resolved itself into a choice between a vidicon or an image orthicon type of camera tube. The image orthicon tube is considerably larger than the vidicon tube and costs approximately 25 times as much per hour for replacement. Present vidicon tube replacement costs are about $0.08 per hr compared to approximately $2.00 per hr for the image orthicon tube. Image orthicon tubes generally have greater sensitivity and are not subject to lag or smear with moving objects, require less operator attention to adjust camera output under varied light conditions and can accommodate a large contrast range. Although new developments in the image orthicon field have reduced the cost of cameras to approximately $20,000, the cost is still prohibitively high for use in closed-circuit television.

The development of vidicon tubes to a point where night application is now practical has made the use of the vidicon camera a practical tool. The vidicon camera also requires less circuitry, is easier to set up, and has a better signal to noise ratio under good light conditions. The disadvantage of sensitivity has been largely overcome with the newer, better vidicon tubes and the lag or smear of the moving object is noticeable only at night when the headlights have a tendency to provide a smear as the vehicle image moves across the monitor screen.

Experience with the 16 camera chain in operation has shown that the tubes can operate or have operated over twelve months on a 14-hr per day basis and are still providing high-resolution pictures. Until the image orthicon type of camera becomes considerably more economical, a choice of basic camera type will not be too difficult for normal traffic application. All specifications pertaining to cameras in this report refer to the vidicon-type camera.

Scanning

A second major selection in basic camera characteristics is the choice of types of scanning. Two major scanning systems

are random interlace and positive interlace. Random interlace cameras cost from \$1,000 to \$2,000, and positive interlace cameras cost from \$3,500 to \$5,000. Random interlace cameras have approximately 13 tubes compared to over 30 tubes for the positive interlace. Normally, maintenance costs of electronic equipment are proportional to the number of tubes. In complex systems with many accessories, the difference in total maintenance cost may be nominal. Because of the big difference in cost, the two systems are discussed in detail.

The picture on a television screen is produced by the rapid movement of a beam of electrons which is viewed as a spot of light moving from the left to the right in horizontal sweeps and successive sweeps are formed from the top to the bottom forming a complete picture. As this small dot of light rapidly sweeps the screen, it varies in intensity to produce the range of color from black to white and a special material on the picture tube retains the image for a fraction of a second so that a complete picture is apparent. The light sweeps horizontally across the picture tube 15,750 times a second and sweeps from the top to the bottom 60 times a second. This results in the dot producing 262 ½ sweep lines as it moves from the top to the bottom. As it again sweeps the screen required for a complete picture, it now starts one-half a sweep late and the resulting second 262 ½ sweep lines interlace or go between the first 262 ½ lines. If the interlace is perfect, a picture consisting of 525 sweep lines is developed. All expensive broadcast equipment and positive interlace closed-circuit equipment provides this interlace in its transmitted signal.

Positive interlace requires that the camera have an absolute 262 ½ relationship between the vertical and horizontal drive circuits. This is usually accomplished by having one base oscillator operating at 31,500 cycles per second, and special countdown circuits are used to obtain the horizontal frequency of 15,750 cycles per second and the vertical frequency of 60 cycles per second. Such countdown circuits should count more than seven steps in any one stage if good stability is to be attained. Generally speaking, the positive interlace cameras are also better constructed and usually have horizontal resolutions higher than those produced by the random interlace cameras.

An economical and simple scanning system known as non-interlaced or random interlace sweep involves the use of a separate horizontal and vertical oscillator with no tied relationship between the two frequencies. If both the camera and monitor have completely isolated sweep circuits, successive vertical sweeps or fields will not be exactly on top of each other or exactly interlaced. Actually, each 260 some odd sweep lines will show that adjacent lines appear to be moving closer and farther apart with respect to each other. In the resultant picture, it will appear to have considerably more than 262 lines but probably something less than 525 and will be varying between these two figures.

The choice between positive interlace and random interlace is usually one of money and maintenance because the complexity of the positive interlace usually doubles or triples the circuitry of the camera and increases the cost of maintenance.

The primary difference from the standpoint of the average observer between random interlace and positive interlace is that the picture appears steadier with positive interlace. The random interlace picture may appear to be somewhat watery. A second difference which is harder to discern in the average traffic picture is the difference in vertical resolution or the ability to discern the difference between horizontal lines as they increase in number. This might be explained if the camera were directed at a series of horizontal lines or say a venetian blind where the slats were increased in number until they could no longer be counted. In positive interlace closed-circuit television, this number would be approximately 375 horizontal lines in the height of the picture. In random interlace, this number will vary from approximately 200 to 300. If the horizontal and vertical oscillator can be kept completely isolated so that they do not synchronize on each other, a vertical resolution of nearly 300 lines can be obtained.

In the cheaper random interlace cameras, the two frequencies will synchronize on each other, and successive fields will trace on top of each other with no interlace. The resultant picture caused by this line pairing will be composed of 262 or 263 sweep lines instead of 525 and the vertical resolution will be approximately 200 lines. Loss of resolution due to line pairing is actually greater than the difference noted between positive interlace and a good random interlace.

The choice of a monitor that has no crosstalk or feedback between the vertical and horizontal oscillators is extremely important to keep pairing from occurring. Even in a home television receiver which receives a nearly perfect interlace type of signal from the broadcast station, pairing is quite common. In various experiments and demonstrations, it was found that the monitor was more often responsible for the pairing than the camera. In fact, several demonstrations with supposedly interlaced cameras being used produced pairing because of the monitor being used.

Original specifications for the TV project did not necessarily require a positive interlace camera. Successive observations between the two types of cameras did not prove that the difference in vertical resolution between 300 and 375 lines was significant enough to require positive interlaced cameras. The cameras were set to view the freeway from a bridge that crossed the freeway, and traffic was viewed for a distance of 1,700 ft. The difference in resolution between the random interlace and the positive interlace camera did not vary the detail noted by more than a few feet on the freeway. In other words, if a stalled vehicle could be determined at 1,600 ft in the positive interlace camera, it could be seen at 1,500 ft in the random interlaced camera, provided the monitors were of such quality that line pairing did not occur.

Many other requirements in the specifications were generally found or could only be guaranteed in the higher grade cameras. Therefore, the lowest bid as supplied by General Electric Company was based on their positive interlace, TE-9 transistorized camera. Additional studies will be conducted to determine whether positive interlace is a necessary characteristic.

Scanning Rates

One decision not too difficult to make at the time of the project, but which might be considered at a later date, involved the choice of scanning rates. All commercial broadcast television in the United States is 525 scanning lines per frame or picture or as mentioned 262½ scanning lines per field. With proper interlace, this gives a positive vertical resolution of about 375 lines. Vertical resolution is directly proportioned to the number of sweep lines forming the picture and is equal to approximately 65 percent of the number of sweep lines. Although it is easier for manufacturers to provide high horizontal resolution, it appears that the greatest limitation to over-all readability lies in the lack of vertical resolution. There does not seem to be much justification for horizontal resolutions exceeding 600 lines unless the vertical resolution is increased proportionately. It is possible to obtain closed-circuit television with scanning rates of 619 or 825 lines per frame. This would increase the vertical resolution to approximately 420 lines or 550 lines, respectively. This type of equipment was not demonstrated in operation on the freeway because it was not commercially available from United States firms. Such cameras are available from French firms and are presently being built for the military by some U. S. firms. These cameras will be available from American camera manufacturers in the near future but may be more costly. Such equipment, if available, should certainly be studied before final specifications of a large complex system are written.

Horizontal Resolution

The lower cost random interlace cameras easily produce horizontal resolutions of from 300 to 400 lines. This equipment is primarily used with standard broadcast television receivers to provide an economical closed circuit television system. They are generally used in limited applications under ideal light conditions.

It does not increase costs to provide over 500 lines of horizontal resolution with the camera because it only requires higher quality video amplifiers in the camera and monitor circuits. Horizontal resolution is proportional to the frequency-handling capabilities of all amplifiers in the camera chain. The frequency band width necessary for a particular resolution may be roughly calculated by multiplying the number of sweep lines per second by the number of light changes required per sweep. Because standard broadcast television uses 525 sweep lines and produces a complete field 30 times per second, the picture is formed by 15,750 horizontal sweeps per second. To produce a

horizontal resolution of 600 lines, the sweeping dot of light must go through light change cycle 600 times for each sweep or 15,750 × 600 = 9,450,000 cycles per second. A megacycle is one million cycles and the preceding changes would be designated as 9.45 megacycles. In actual practice, 600 lines of horizontal resolution can be obtained from amplifiers rated at over 8 megacycles. Because most monitors available for closed-circuit television have video circuits capable of passing 8 megacycles, additional costs are found only in the video circuits for the camera.

If the resolution is to be increased above this amount, additional circuits such as aperture correction will be necessary and are usually found on higher priced cameras.

Tests indicated that the difference in resolution from 300 to 550 lines is worth the additional cost. Therefore, it was specified that the cameras would deliver 550 lines of horizontal resolution. Actually, the camera in operation delivers considerably over 600 lines and at the time of installation many of the cameras were delivering pictures exceeding 700 lines of horizontal resolution.

Video-Band Width

Video-band width is the technical name used to designate the ability of an amplifier to handle a range of frequencies necessary to produce a picture. A video amplifier is actually an ultra hi-fi amplifier. The hi-fi fan, who is familiar with figures 0 to 20,000 cycles for his audio amplifier, will appreciate the capabilities of an amplifier that will amplify all frequencies from 0 to 8 megacycles (8,000,000 cycles) ±½ db. The need for band width is directly proportional to desired horizontal resolution, as shown in the discussion on horizontal resolution. Generally, a camera's capabilities are shown by lines of horizontal resolution. Line amplifiers and monitor capabilities are shown in band width. Naturally all components must have equal capabilities or the output will be only as good as the information passed by the poorest amplifier.

In the equipment installed on the John C. Lodge Freeway, the amplifiers are operating close to 10 megacycles as was proved by the fact that pictures exceeding 700 lines of horizontal resolution were obtained. With the present state of the art, any specifications written that exceed 8 megacycles will considerably limit the amount of equipment that can be bid for a project.

Transistorization

A third major selection of basic camera characteristics is the choice between a camera using vacuum tubes and one using transistors. When the original specifications were written, there was not much of a choice. Only three transistor cameras were available and none seemed to meet desired requirements. Since then, there have been rapid transitions to transistorized cameras, and one company included its new transistorized camera as an alternate bid. Performance tests proved the superiority of the transistor camera, which is now being used on the project.

Transistorization has made it possible to provide a fully interlaced camera in one small unit. Previous tube-type cameras were forced to use two units so that one unit containing the pickup tube could be small enough for most applications. Besides the greater size, the thirty-odd vacuum tubes created a heat problem and greater failure rate. The transistorized camera has overcome the liabilities of size, heat, and maintenance cost of the interlace cameras.

The maintenance record has shown transistor failure to be negligible. With 59 transistors in each camera there has been approximately one transistor failure per month in the whole system. Nearly as many vacuum tube failures occurred in the monitors with only 25 percent as many components. Operational experience with this camera has proved that any future installation should be studied for the possibility of using transistorized cameras.

Figures 2 through 7 show the camera in present use. The camera is 5½ in. in diameter, and 11¾ in. long. Figure 6 shows the cover removed and the layout of all parts on three plug-in boards. These boards are completely wired and all transistors are plug-in for easy maintenance. Figure 7 shows the camera with plug-in boards removed and access to the vidicon tube and three accessory drive motors. One motor

Figure 2. Transistorized camera with 6-in. telephoto and $1\frac{1}{2}$-in. wide angle lens mounted on turret (standard desk telephone used for comparison).

drives the turret, the second drives the iris on the lens in use, and the third drives the vidicon tube backward and forward for focus. Each motor is remotely controlled from the control center by the operator.

The camera uses one miniature vacuum tube to amplify the extremely weak video information received from the vidicon tube. Vacuum tubes have a lower noise level than transistors and have an advantage for amplifying weak signals. Records show that this one tube (type 6021) lasts less than one year and has a higher failure rate than any other component. Present design has eliminated this vacuum tube.

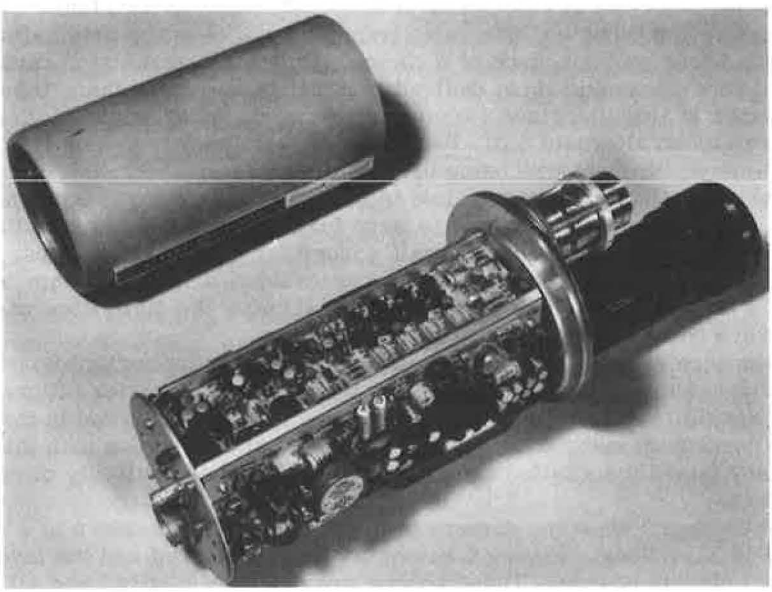


Figure 3. Transistorized camera with cover removed exposing components.

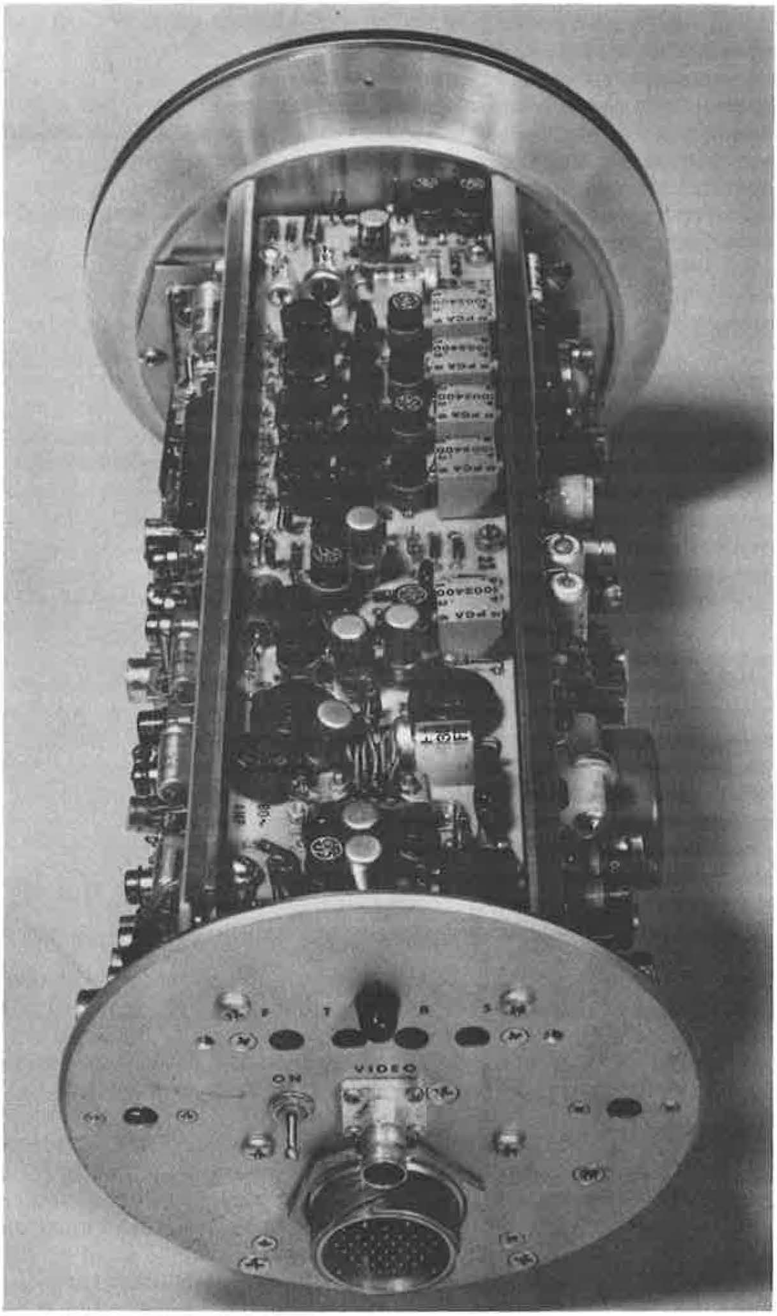


Figure 4. Camera with cover removed showing the three separate component boards (rear plate has provisions for input-outputs and field adjustments).

Ambient Operating Conditions

Specifications required that the camera be capable of operating within specifications under the following ambient conditions: temperature +10 to 100 F; humidity, 10 to 100 percent; altitude, 0 to 10,000 ft. It was also required that no arcing would take

Figure 5. Only vacuum tube used in camera (used in first stage of video output).

place or that the equipment would not be damaged if it was turned on or operated between the temperatures of -10 and 130 F. The cabinets for which the cameras were to be installed were designed to be heated in the winter and ventilated in the summer. Specifications on vidicon tubes indicated that the tube does not produce a good picture if temperature goes below 70 F. The vidicon tube generates some heat and is enclosed in the camera.

It was found that the cameras produced a very satisfactory picture with cabinet temperature down to 32 F by leaving camera power on continuously. When the system is not in operation, the vidicon tube is remotely capped while the turret and camera power remains on. This method of operation has required less maintenance as the camera components are always heated. In the large camera enclosures used by the project, it has been very difficult to provide enough heat to maintain a cabinet temperature above 60 F at all times. If the camera power can be left on at all times, the cabinet surrounding the camera would not have to be heated until the temperature drops below freezing.

Camera Encasement

The camera itself must be in a practically air-tight case. To ventilate properly the camera housing in which the camera is installed, a fan has to circulate air past the camera. In spite of the installation of filters, large amounts of salt spray and dust are collected inside the housing. This foreign material can enter the camera through the adjustment openings (Fig. 4) on the rear plate of the camera and cause serious damage. This foreign material must be kept out of the camera working parts, and any future case design should eliminate the condition.

Sensitivity

Sensitivity is a rather difficult requirement to specify and to check in terms of physical qualities; however, if the camera can deliver 1 v of video in the vidicon tube when the scene brightness is below 10 FL and the latest, most sensitive vidicon tube is used, adequate night pictures will probably be obtained. Actual observations of equipment operating at night on the proposed site will be the only true method of indicating whether all of the circuits have been properly designed to give the best night pictures. Several cameras produced good pictures in the project area with a scene brightness of less than 2 FL. This night picture was only available if lens with an aperture opening of greater than F2.5 were used. Night visibility is not entirely due to sensitivity alone. Oncoming headlights can affect automatic gain controls in the camera which can materially reduce seeability. Other characteristics (such as gamma correction and types of lens) also influence the total picture.

Automatic Target Control

In several tests on the freeway, it was determined that automatic target control was an absolute necessity for use on a freeway. In the daytime, a picture with scene brightness of approximately 5,000 FL exists and at night this light will be less than 2 FL. The

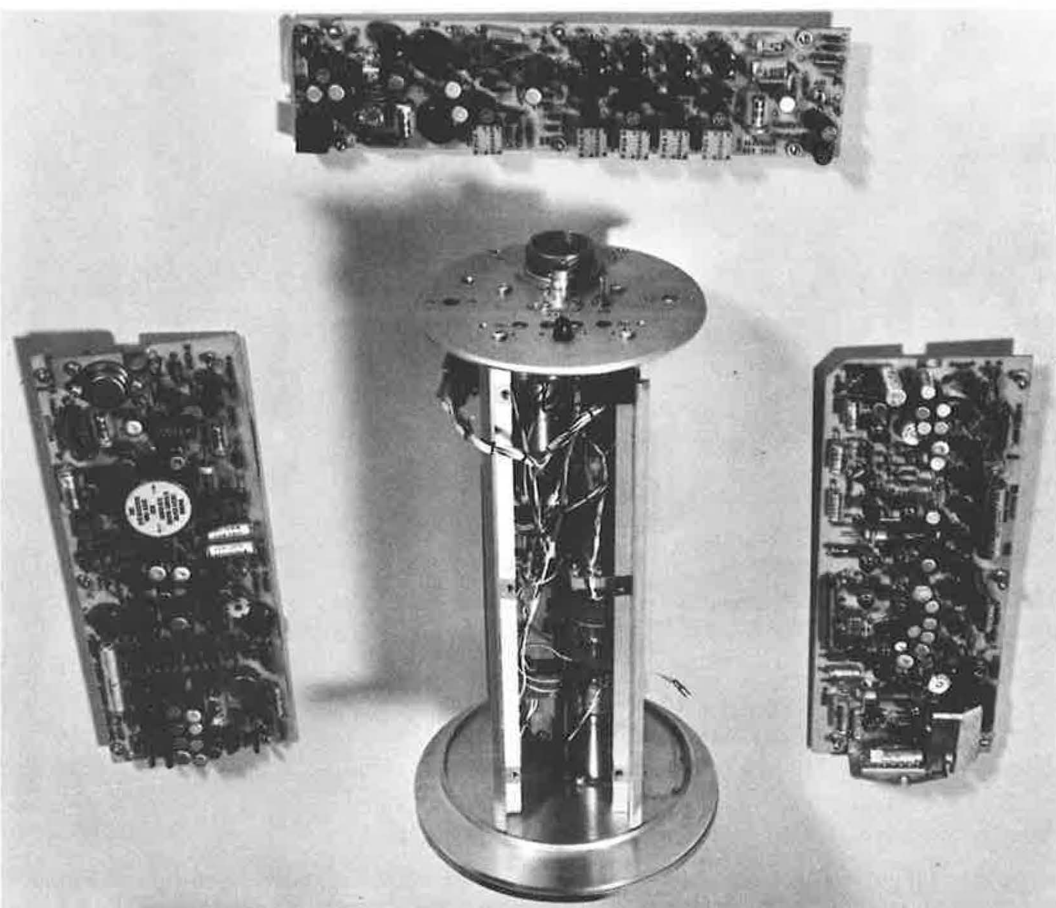


Figure 6. Camera stripped of boards containing all circuitry for power, video, and synchronization, showing ease of removing parts for maintenance.

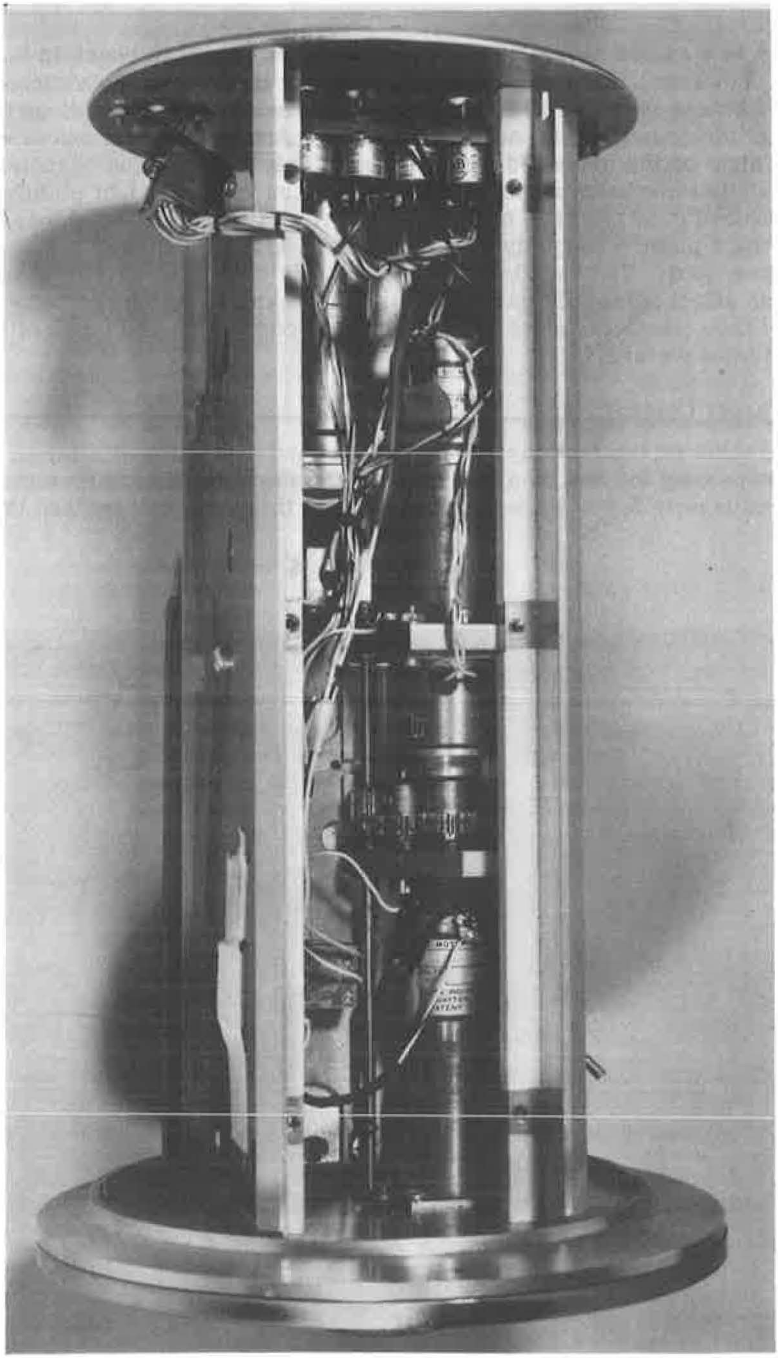


Figure 7. Camera with all component boards removed, showing focus, turret, and iris motors.

automatic target control actually varies the gain or output of the vidicon tube, depending on the brightness of the picture. Without this operation during the daytime, an operator would have to change the aperture of the camera lens or manually regulate the

gain control every time the sun went behind a cloud or a shadow fell on the picture area. If the camera was set for a good picture on dull days, the picture would be overly bright and smeared when the sun came out. During the daytime, the picture brightness can vary from 5,000 to as low as 100 FL. At nighttime, however, it is possible that the automatic target control can be a liability. The over-all night level of the area is constant because of street lighting.

Some of the tests made with various manufacturers' cameras showed that cameras with an apparent high resolution and high specifications did not necessarily give the best night picture. In fact, one of the poorest night pictures observed had a camera which claimed 2,000 to 1 automatic target control and 600 lines of resolution. As a result of these observations, it was determined that the automatic target control might be actually reducing the over-all picture sensitivity at night. If the automatic target control circuit is sensitive enough to react to the light received from a few headlights, it could cut the over-all sensitivity down, reducing visibility to balls of light from the headlights. Inasmuch as the headlights are moving, no harm seems to be obtained if the sensitivity of the camera can be kept at a maximum at night and allow the image of the headlight to smear.

As a result, specifications were written so that the camera would be provided with a switch that would remotely disable the automatic target control circuit for nighttime operation. This should be provided in any future project because of the great variation observed in nighttime operation of the various cameras. A camera was provided with a switch to turn off the automatic target control at night. The camera was operated with ATC at night producing a good picture, and no noticeable difference could be determined when the ATC was turned off. The particular automatic target control circuit used apparently makes use of the average light available to the vidicon and not to the light available in a small area as from a headlight. At the present time, there is no means of switching off the automatic target control at night.

Gamma Correction

Gamma correction is the characteristic installed as a special circuit which expands or increases the ratio between bright and dark objects. Generally, the output from a camera pickup tube would produce a flat or dead picture. In other words, the dark or blacks and white or light colors would all appear in various ranges of gray. The gamma correction circuit is actually an expansion circuit that makes the lighter colors whiter and the darker colors blacker and in reality returns the picture to nearer its original range of color. At nighttime, there is not a normal range in color between black and white. The whole area has a very small range between the different shades of gray. Multiplying or amplifying this range of color would not normally be observable to the average person. However, the brightness of the headlights is many times brighter or whiter than any other part of the picture. To amplify this range only amplifies the problem caused by the headlights. In going over the specifications of the various cameras, some successful and some not, it appeared that the gamma correction circuits might have an effect on reducing night visibility.

As a result of these observations, it was determined that the cameras should be supplied with facilities to change gamma correction and materially flatten the ratio of the brights to the dark. It was believed that this reduction would be advantageous at night, and would not materially reduce the picture quality in the daytime. After the cameras were delivered, one camera was wired by the factory and made available for trial making use of a lower gamma factor and which theoretically would produce better night pictures. On the General Electric camera used, however, no noticeable difference was determined, and it was again converted to standard operation.

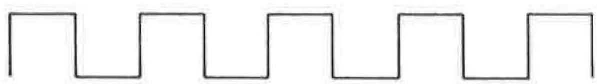
A change of gamma correction in the cameras used involves only a change of one resistor and one condenser and does not take long to accomplish. This item should be observed on any camera before it is delivered because it might still be possible that a camera constructed of a different circuitry might be improved with a change in gamma correction.

Aperture Correction

Aperture correction is another term which adds to the confusion from the myriad of new terms confronting the prospective purchaser. This feature, which can be easily confused with aperture control of the lens, is actually a camera circuit used to accentuate changes in the output of the vidicon tube.

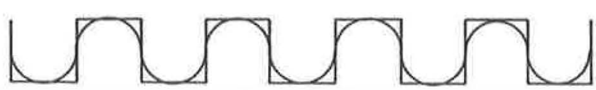
The image formed on the face of the vidicon by the lens is ¾ in. wide and ½ in. high. The video intelligence is taken from this image by a process similar but in reverse to the method of producing the picture at the monitor. A beam of electrons is directed at the back of the vidicon face which is also a photoconductor layer, and as this small beam sweeps the picture, the current varies proportionately to the light on this particular section of the image.

Because the beam also sweeps this picture in 525 lines, the size of the beam must be very small if high resolution is obtained. Actually, the size of the electron beam cannot be infinitely small and the output is not as nearly perfect as desired. A camera producing 600 lines horizontal should be able to reproduce the image of a picket fence with 600 slats shown on the ¾-in. width. If the electron beam was infinitely small, the voltage output would vary in amplitude exactly as the light change of the pickets on it would form a square wave:



Actually, the beam has dimension and as it sweeps from light to dark light level, the output changes gradually and the resultant output wave is rounded in shape:

Aperture correction is an electronic circuit that reshapes the wave and squares it to the desired shape:



The resultant output is a sharper picture and if resolution exceeding 400 lines is desired, such circuitry is required.

CAMERA ACCESSORIES

Automatic Light Control

Automatic target control, as specified earlier, is capable of reducing the output of the vidicon tube to levels that can be handled by the subsequent amplifier circuits. However, to obtain good nighttime pictures, the lens used must be opened to F2.5 or greater. No camera was found capable of automatically adjusting to the complete range of light from night to bright sunlight with the lens wide open. There is also a possible danger that the vidicon could be permanently damaged if the lenses were opened to F2.5 or greater and happened to focus on a reflection of bright sunlight from a parked

vehicle or any other reflective surface. Observations would indicate that ideal pictures during the daytime are obtained on most cameras if the lenses are set between F8 or F11.

The specifications were, therefore, written to require that a lens aperture change should be accomplished by remote iris control of at least two lenses in a turret or that the introduction of a neutral density filter should be accomplished. Several cameras studied were available with a neutral density filter that could be rotated between the lens and the vidicon tube and reduce the amount of light available to the camera. This appears to be a simple method of reducing the light level by remote control, or in the case of some equipment, this filter control was connected to a light cell at the camera site.

The cameras on the project use an iris drive motor which is contained in the small camera package. As the lens rotates on the turret, it engages a small gear connected to the iris drive motor. This motor, which is remotely controlled from the control center, allows the operator to change the iris on any lens which is being used.

Iris control does provide the most flexibility of any system that was demonstrated. It is now possible to install four lenses on the camera and be able to switch from one lens to another and to close or open the iris as necessary for night or daytime operation.

Normally, only two lenses are used on a camera. It would have also been possible to use four lenses in a turret, two of which were set for nighttime operation and two of which were set for daytime operation. Though this method satisfies most conditions, it would not allow optimum settings during cloudy days or at dusk, and it would not give a blank position now used to blank out the vidicon tube when the camera is not in use. Blanking out of the vidicon tube seems to be mandatory in the use of closed-circuit television. Other agencies have had problems with images actually burning on the screen. This results in the camera transmitting a picture that it has seen for a period of time even when it is not directed at the scene. The problem only results if a camera is permanently stationed and looks at a target for considerable time. Because it is possible to change the camera scene by remote turret control, this is not a problem in this particular case.

Lenses

One of the first problems presented in the choice of camera equipment was the selection of lenses to be used in observing traffic operations. A most interesting device having a lot of appeal is the zoom lens which is presently available from several lens manufacturers. This lens is capable of showing a general picture with a standard lens view as would normally result from a regular lens on a camera and of "zooming in" on a particular target by remote control for a closeup at the desire of an operator.

Although one particular zoom lens is available at an F2.7 rating, this aperture setting is only available when the lens is in its normal setting. As the setting is changed to a zoom position or closeup position, the aperture setting is reduced to F5 or F6, which means that it would obtain no pictures at all during nighttime operation. The inability of the zoom lens to handle low light conditions, in telephoto position, ruled out this device.

After considerable investigation, it was found that lenses were available in a telephoto type down to F2.3 or actually F2.0. At the present time, 1-in. or 25-mm lenses at F1.5 are used throughout the project. This provides a consistent normal field of view from each bridge and gives the operator a standard field for estimating velocity and travel times of vehicles through the area. A telephoto lens of 6 in. or 150 mm for closeups of an actual occurrence that the operator wishes to investigate is also used. This lens is an F2 and is of considerable size in relation to the camera (Fig. 8). These lenses were originally delivered with click stops for different F-stop settings but had to be exchanged for lenses without any resistance to a change in F-rating for smoother operation. The present arrangement of lenses in a four-lens turret with remote iris control of each lens is very satisfactory. It may be possible that if the field view is a longer distance, an additional 9- or 10-in. lens could be installed for daytime operation

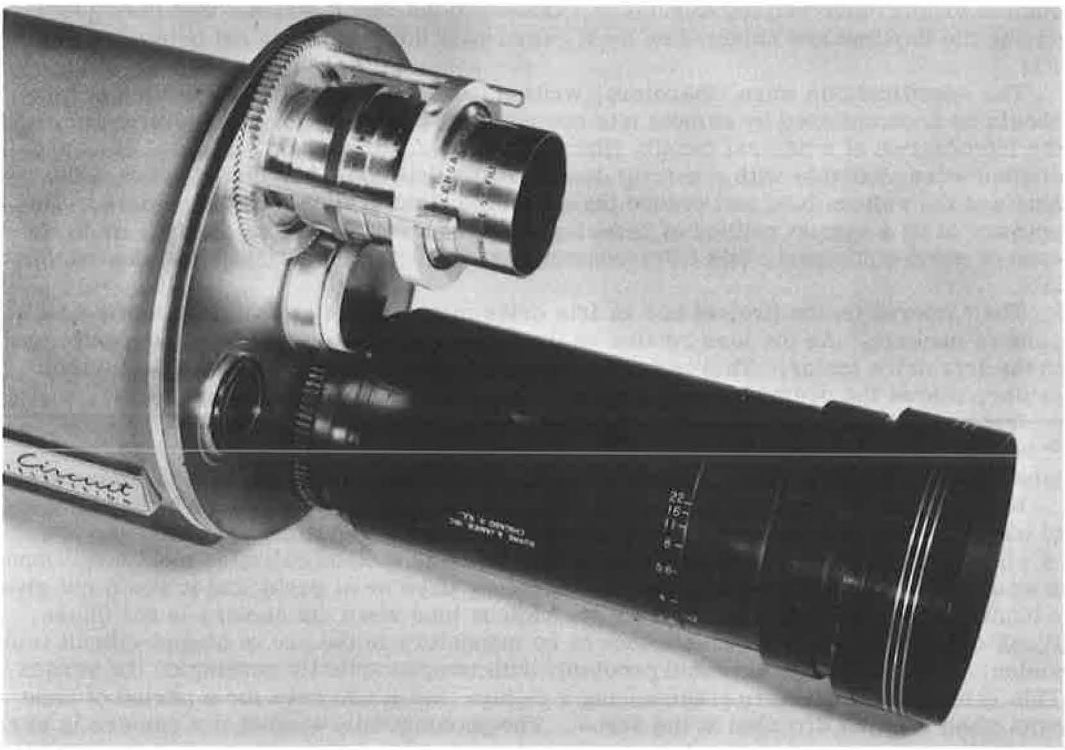


Figure 8. Typical lenses used for viewing traffic: large 150-mm telephoto lens for closeup viewing, 5-mm lens for general wide-angle viewing.

as a third lens. A lens larger than 6 in. was not available with an aperture rating of greater than F2.5 and therefore would not make nighttime operation practical. Even if such a lens is available, it probably is so large that it will not lend itself to operation in a turret with other lenses. The present 6-in. lens is approximately 8 in. long and weighs approximately 4 lb. Telephoto lenses of greater capabilities are available, but aperture openings are smaller.

Remote Focus

Each camera is equipped with a self-contained motor and remote focus mechanism which moves the vidicon tube backward and forward until it is in focus with the particular lens that is being used. This, of course, is a necessity because a change in lens is accompanied by a change in focal length. Limit switches are provided in the camera to keep the focus drive assembly from overtravel and jamming. Experience with this mechanism has been good with few failures.

Remote Turret

Because only two lenses were deemed necessary for this project, the specification required a minimum of a three-position turret. The camera supplied has a four-position turret, one blank position should always be provided which can be capped to remove light from the vidicon tube when the camera is not in use. Power to the camera is left on at all times. However, when it is not being used, the vidicon tube is capped so that the light is cut off and the tube can rejuvenate itself.

The turret is required to index accurately to a positive detent from a remote control panel. The camera has this motor inside of the camera package which makes a neat, easily serviced unit. The entire camera, complete with lens turret, remote iris

control, and remote focus is complete in one small package and can be replaced with a spare camera in a matter of minutes.

Pan and Tilt Assembly

To make proper use of the telephoto lens which has a very small field of view, a pan and tilt assembly is mandatory. Probably no other manual control receives more operation during the day than the pan and tilt assembly on each camera. This makes it possible to scrutinize any activity within the field of view by the use of the telephoto lens. Because choice of camera sites made it possible for all areas to be viewed within a 60° area, a cabinet housing was designed so that the pan and tilt assembly would operate inside of the housing (Fig. 9). By using the pan and tilt assembly inside of the camera housing, a standard lightweight pan and tilt assembly that was protected from ice, snow, and vandalism could be used. Other camera locations might make a greater field of view necessary, in which case a smaller camera housing would be used and the entire housing would be operated by a pan and tilt assembly. A pan and tilt assembly that operates the entire camera enclosure is more heavily constructed and cannot be entirely protected from all types of vandalism. Either the entire enclosure area must then be fenced off or the camera mounted on top of a building or on top of a pole in such a way that it cannot be readily reached by unauthorized personnel.

The use of a pan and tilt assembly has an additional advantage which was not considered at the time of the writing of the specification but has increased the usable life

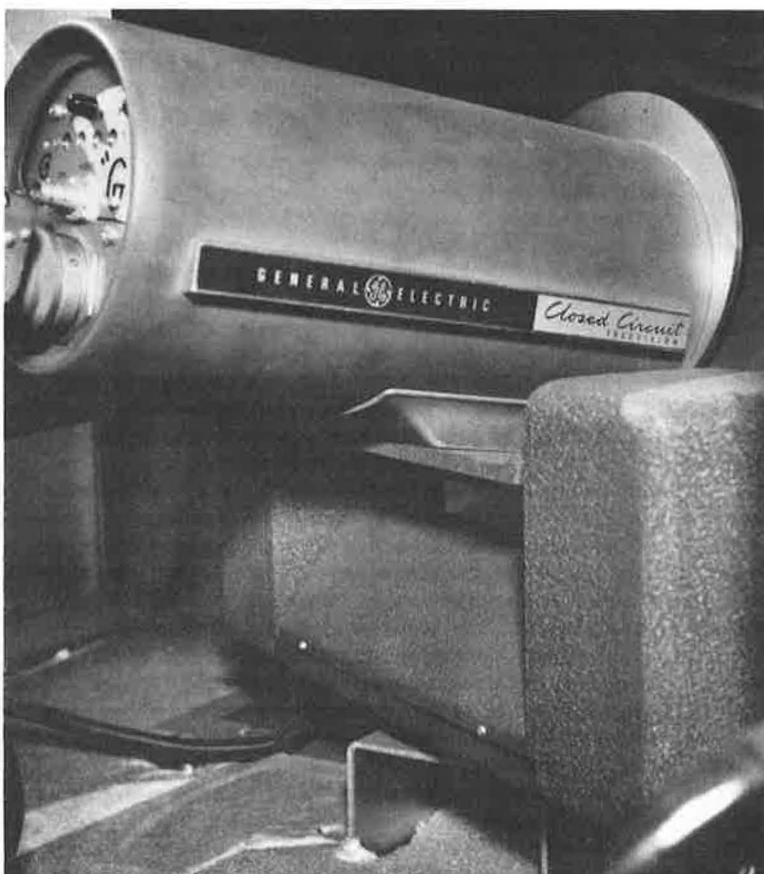


Figure 9. Camera mounted on pan and tilt assembly in field housing.

of the vidicon tube by several times. As previously mentioned, a camera that looks at the same scene all of the time soon has an image burned into the photoconductive layer of the vidicon tube and that picture is transmitted no matter where the camera is aimed afterwards. Because the pan and tilt assembly is used many times a day by the operator, a picture is not burned into the camera tube and, therefore, is not a problem. The pan and tilt assembly is equipped with limit switches so that the camera can pan 30° to the right or 30° to the left and 30° below horizontal. These limit switches automatically stop the pan or tilt movement at these points so that the lens does not hit the sides of the cabinet.

CAMERA ENCLOSURE

Housing

The camera housing specifications were developed around two drawings (Figs. 10 and 11). Because many bridges that cross over a freeway system are not at right angles to the freeway, the housing was designed in two sections so that the upper section could be rotated and allow the camera to be oriented with the freeway below. Although the basic design has proven to be a good one, many of the changes or incorporations made by the manufacturer have not proven to be entirely satisfactory. The lower cabinet was made considerably larger than originally specified at the request of Michigan Bell Telephone Company which obtained the low bid contract for supplying the transmission facilities. The specification required certain temperature limitations to be met and the design was to incorporate enough heating and ventilation to maintain these temperatures under all weather conditions. Due to the short length of time given to the contractor after the awarding of the contract before the final installation was to be completed, a very limited amount of design work went into the cabinet by the manufacturer. Actually, the local sales representative worked with a metal fabrication shop and settled on a design that left something to be desired. A considerable amount of money was spent rebuilding the cabinet heating and ventilating facilities to meet specifications. The cabinet housing was finally insulated and heaters installed in both upper and lower sections. The existing cabinet meets all requirements from the standpoint of vandalism and operation.

One problem encountered with the present cabinet is that the design with special

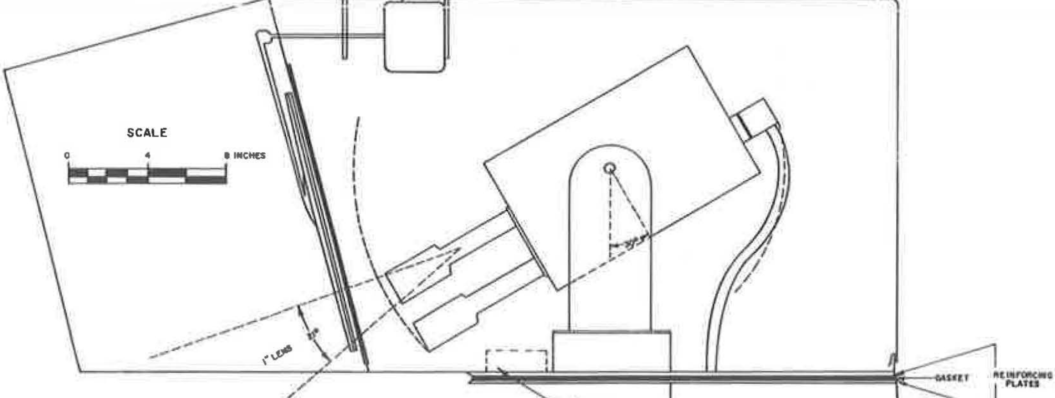


Figure 10. Camera enclosure, side view.

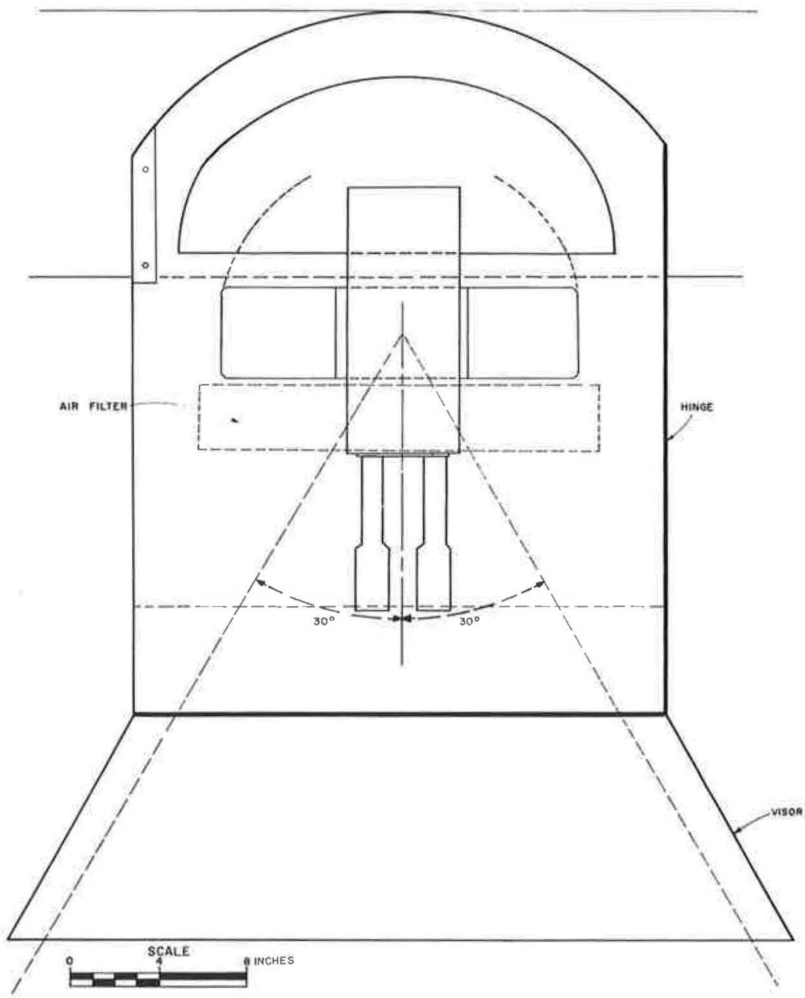


Figure 11. Camera enclosure, top view.

flanges (Figs. 12 through 15) prohibits anyone from reaching the face of the glass through which the camera operates. Although this design has done a very good job of keeping any vandalism from occurring, it has also made it impossible to reach and clean the outside of the glass. Windshield washers were not installed in the original installation because it would still be necessary to refill them on a schedule and it was felt that the normal preventive maintenance routine would also allow for the periodic cleaning of the glass. No great problems occurred with dirty windshields because they do not seem to get too dirty in a period of one month, and if an occasional splatter of rain gets on the glass, the windshield wiper wipes it clean. At the present time, the maintenance personnel have a large tank sprayer with a long, bent nozzle which will reach out over the cabinet and squirt cleaning fluid on the face of the glass. The windshield wipers seem to do a satisfactory job of cleaning the glass. A more desirable design would allow for easier access to both sides of the glass.

The final upper housing was constructed of heavy 10-gage steel and consisted of three access doors. This allows both sides and the top to be opened for easy access to the interior. Actually, the top opening has never been used. The two sides open up and have provided adequate working area. Because of the weight problem, it might be desirable for the cabinet to be designed with aluminum of about the same gage which

Figure 12. Field housing containing camera and related field equipment as seen from shoulder of freeway.

should be strong enough to repel vandalism but might be light enough to allow the top to swivel if properly designed gasket material was used.

It has become apparent that if the cameras are to operate all the time, that heating within the limits specified would not be necessary. The amplifiers provided by the Michigan Bell Telephone Company consist of vacuum tubes which operate 24 hours a

day. In their experience, heat was not necessary in the lower part of the cabinet, so that it now seems that the upper cabinet should have been heated and ventilated by smaller units within it and that the limits of heating should have been much broader. As long as the camera is operated 24 hours a day, it does not appear that the upper cabinet would have to be heated until the temperatures in the cabinet dropped below freezing.

The bottom cabinet requires a considerable amount of ventilation because of the heat given off by the amplifiers and the power of the isolation transformer. The large amount of circulation required to remove this heat is presently taken in through the upper housing. This means that a much larger volume of dirt, silt, and salt are passed by the camera, and this has been responsible for some problems. A future design could separate the two cabinets with two separate ventilating fans, which should reduce part of the dirt problem in the upper housing.

Specifications required that the hinged door should permit complete access to the interior of the lower housing. When closed, the door was to fit closely to the gasketing material, making the housing weathertight and dusttight. The door was to be adequately reinforced and supported so that it could not be pried open with simple tools. The requirements also stated that an adequate locking system should be provided and all locks should be keyed alike. The original lock system devised was a lever lock that operated bolts to lock both the top and the bottom of each door. This device was then locked with a Corbin-type lock into which the key was inserted through a small hole cut in the door. The handles used to unlatch the door were large enough so that vandals could actually twist the mechanism and damage it when it was locked. Therefore, all the handles had to be changed to a much heavier type. Since that time, all of the handles have been padlocked with a standard hardened padlock as used by many power companies and no serious problems have occurred.

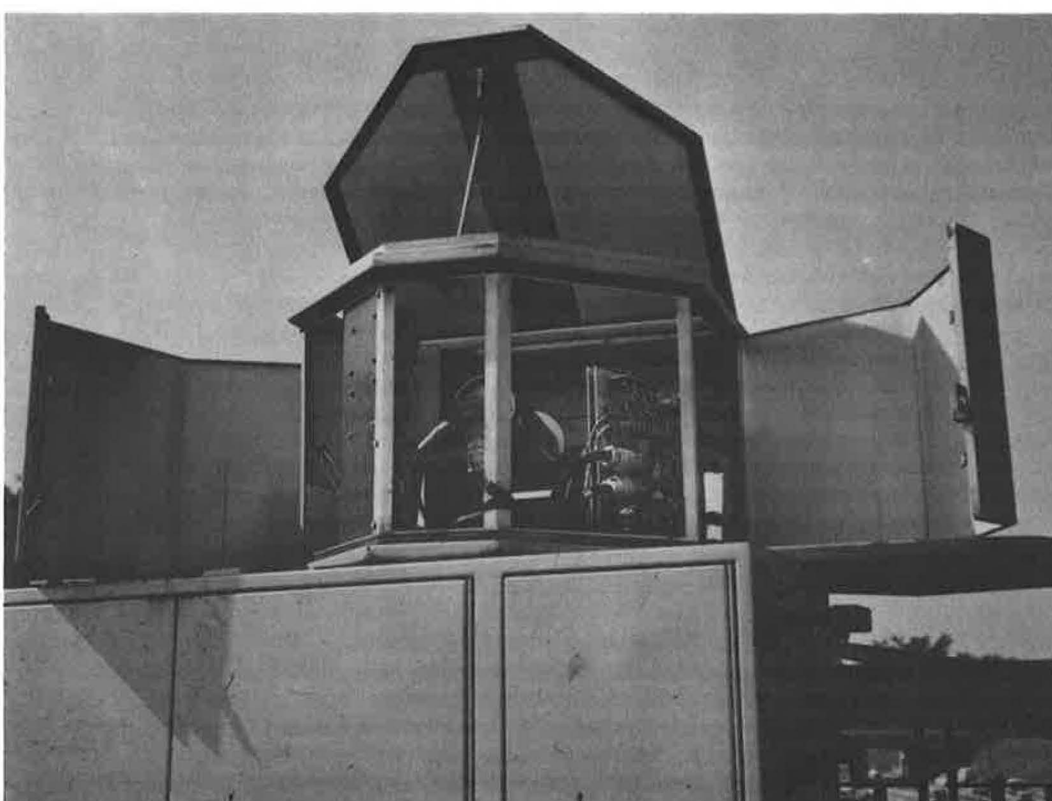


Figure 13. Camera housing, showing upper housing opened for access to cameras.

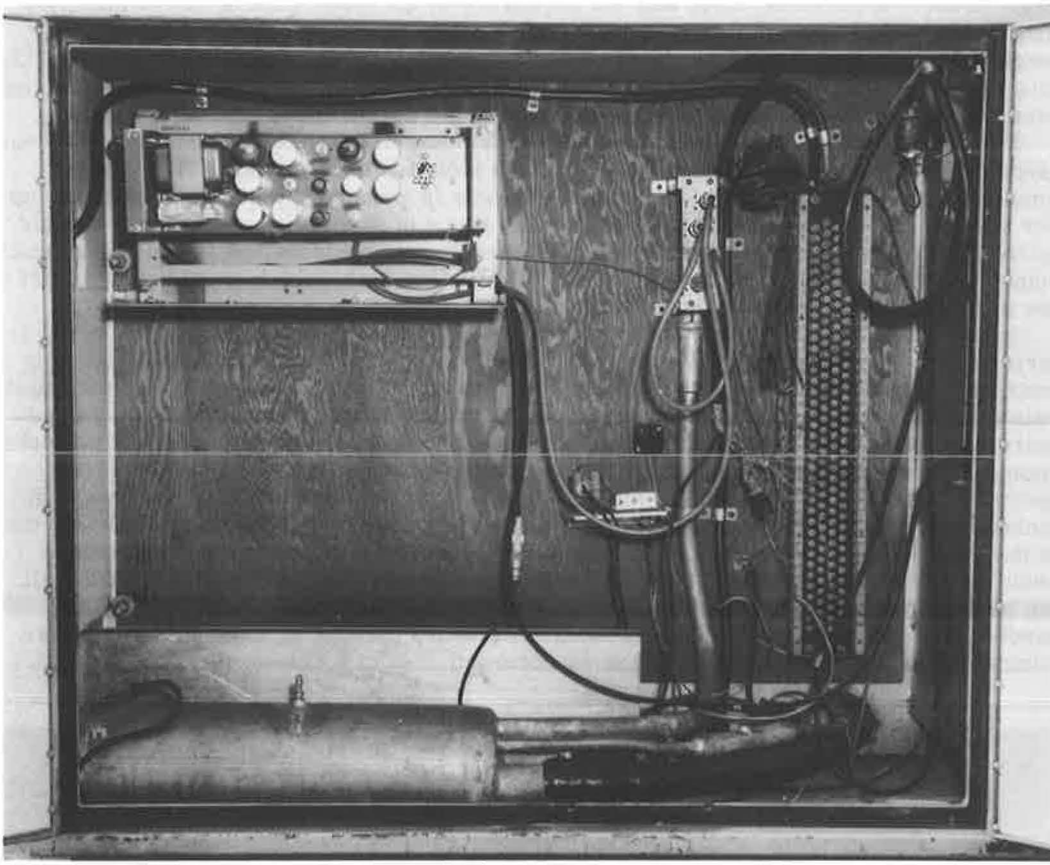


Figure 14. Left side of lower camera housing with doors opened, showing video cable splice, video amplifier, and control terminal board.

Windshield Wipers

All housings are equipped with windshield wipers. At installation, all the windshield wipers were turned on at the same time and turned off at the same time. However, the design of the housings with the extremely large visors has proved to be highly effective and the windshield wipers are only used to wash the windshields or in extreme weather conditions. It has been observed that even then only one or two of the cameras which face a particular direction receive any precipitation on the window glass and need the windshield wiper. Because of the very limited use made of the windshield wipers, the control was rewired so that the operator can operate just the windshield wiper required.

The windshield wiper was designed by the company that designed the cabinet. The windshield wiper blade remains vertical and is attached to a dual-thread screw which runs the wiper back and forth across the glass. The operation is very similar to a level-wind casting rod reel and seems to work satisfactorily. The resulting size, however, was rather surprising inasmuch as the manufacturer chose to use a $\frac{1}{4}$-hp electric motor to operate this drive. In spite of the size of these motors, motor burnouts are still a problem and the entire design of the windshield wiper system should receive considerably more attention. It is possible that the visor could be lengthened or redesigned so that it would be unnecessary to have a windshield wiper at all.

Heating

As mentioned under housing, heating was one of the major problems confronting the

contractor. This item should have been tried and conducted under research conditions using a cold room. Instead, it was assumed that the installation of a 1,000-w heating strip in the bottom of the cabinet would suffice. The equipment was installed in mid-winter. When the heating system was checked out, it was found not to be heating the upper cabinet properly. The electric heating strip did not force circulation throughout the cabinet and during extremely cold weather had very little effect on the temperatures in the upper cabinet. Finally, a 750-w bathroom-type electric heater with a fan was installed in the upper cabinet. It had more than enough capacity to solve the upper cabinet

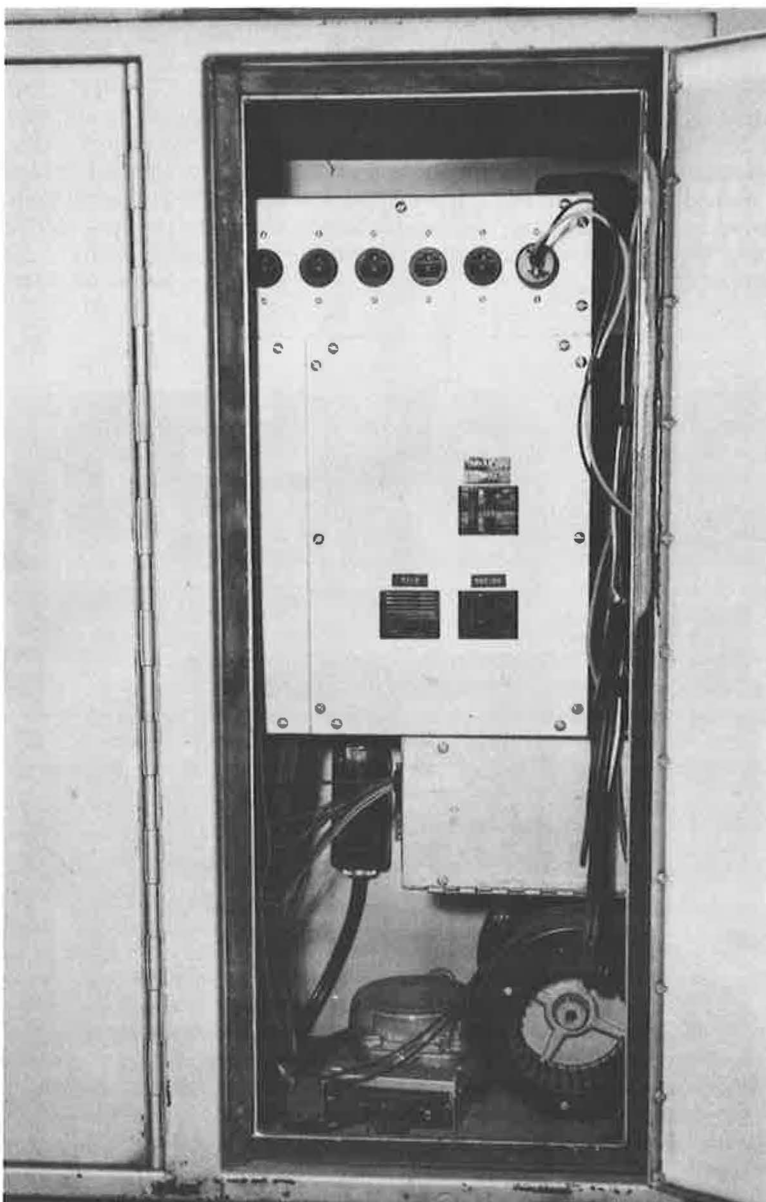


Figure 15. Right side of lower camera housing with door open, showing transformer, ventilation equipment, circuit breaks, and 115-v field supply for maintenance.

temperature problems, and is the only heater now being used. The contractor also insulated all the cabinets with 1 in. of styrofoam to reduce the heating problem further. Temperature recording devices are now being used to determine minimum heating requirements for these cabinets.

Ventilation

A large double-ended centrifugal blower is thermostatically controlled to exhaust air from the cabinets. Fresh air is brought in through a filter in the upper enclosure. This fan has been capable of adequately cooling the cabinet, although for some unknown reason a difference in cooling capabilities between cabinets is obtained.

REMOTE CONTROL SYSTEM

Field Relay Panel

Probably no single item received less attention at the time of design and installation of the system but caused more trouble than the remote control relays. To control all the many functions from the control center, a system of low-current relays was required. The company designed and constructed a standard relay panel which was installed in each camera enclosure. Inasmuch as the project area has 150 pair of control wires available, the control system was relatively simple electrically. A separate wire is used throughout the system for each control function and a separate wire is used for each location.

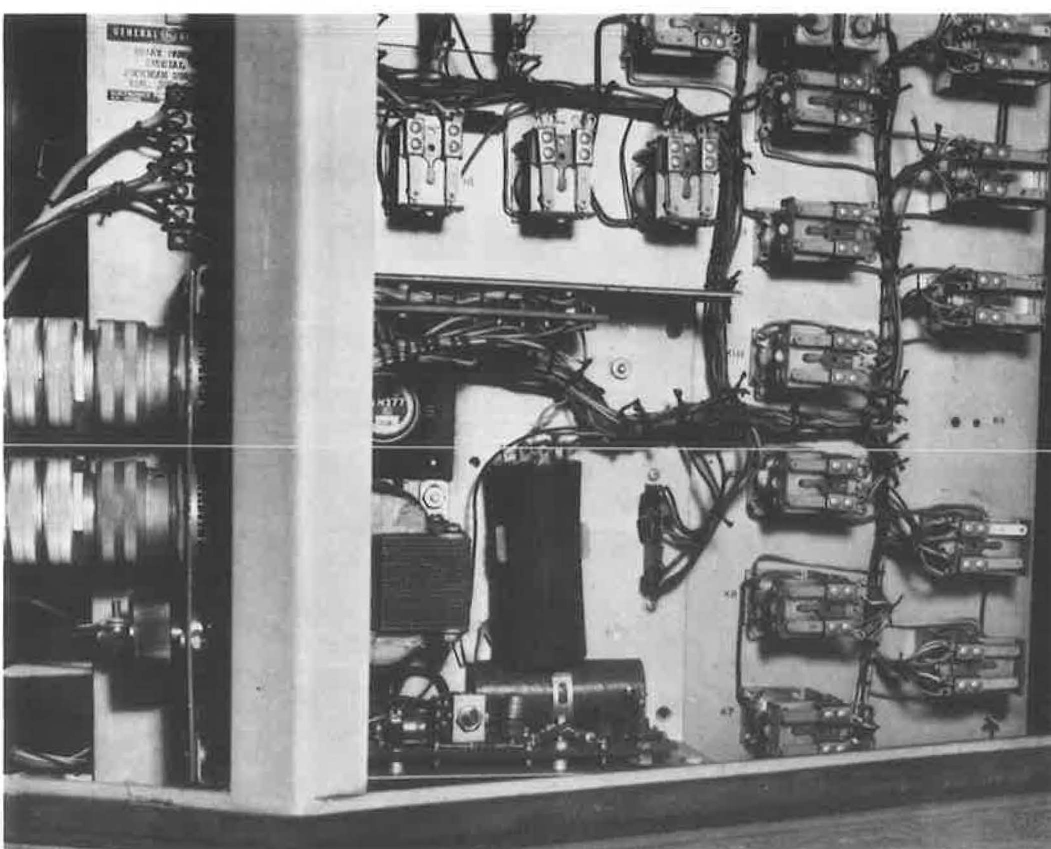


Figure 16. Field installation of control panel, showing exposed relays.

The basic concept of the control has proven to be adequate; however, the relay panel at each field enclosure has been a major problem. Small, standard, open relays were mounted on a heavy sheet of brass stock and installed in the upper housing along with the camera (Fig. 16). It was only a matter of a few days until trouble occurred from these relays The major problem was caused again by the fine salt spray which had settled throughout the cabinet. The contacts would become fouled and the circuit would not work. At the time the specifications for the camera were written, the control seemed such a small part that very little design effort was placed on it. Since that time, a remote control system for the lane control signals was installed throughout the project. This system used heavy-duty plug-in types of relays and was enclosed in a dusttight cabinet. Any future control system for cameras should also specify that relays be of the plug-in type in self-enclosed containers and that the entire relay panel should be enclosed in a dusttight enclosure.

Control Panel

The control panel in the control center which is used to remotely control all of the accessories in the field is in one compact console (Fig. 17). The bottom row of buttons is used to select a particular camera for which the control is desired. The pressing of a button connects all of the relays at that particular camera site to the control lines. The middle row of lever-type switches is used to control the various functions. These switches are spring-loaded and return to their neutral position when they are released.

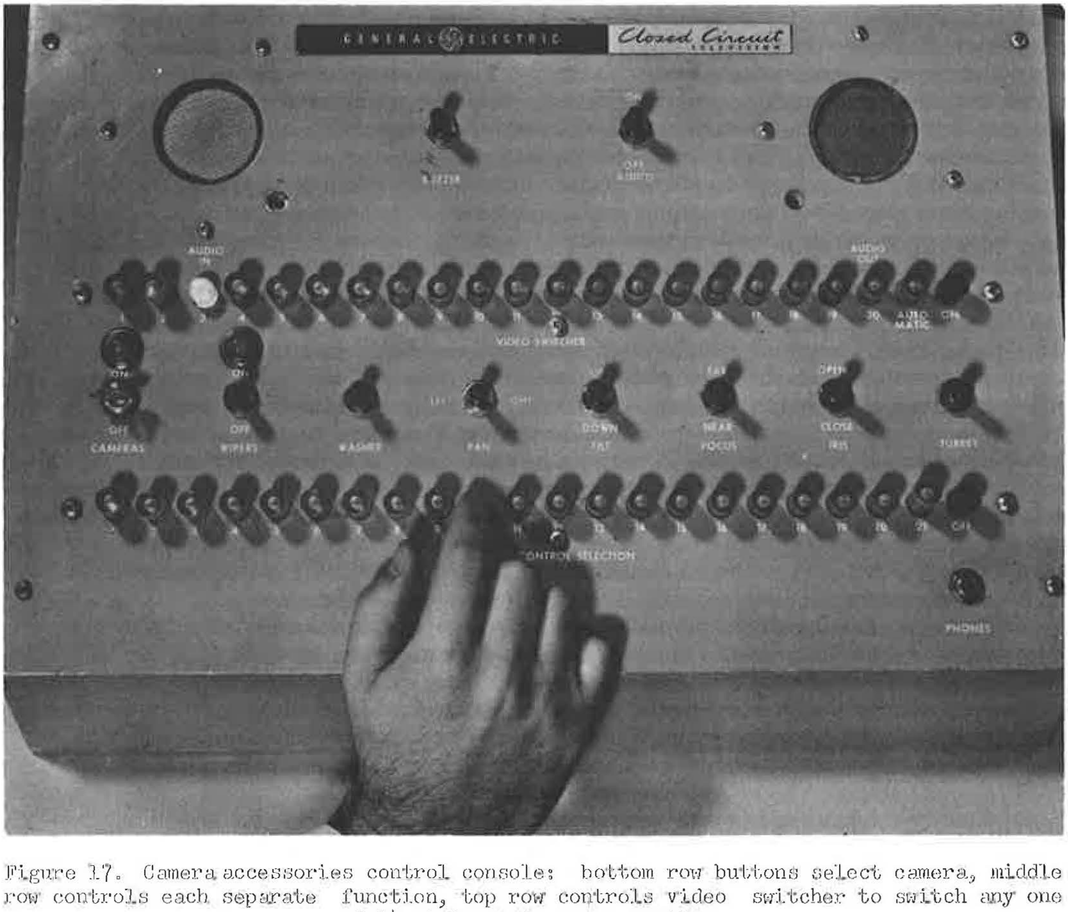


Figure 17. Camera accessories control console: bottom row buttons select camera, middle row controls each separate function, top row controls video switcher to switch any one of 14 pictures to spare monitor.

This principle of control has proved satisfactory although the particular switches chosen for selecting the various stations have not proved to be overly reliable. A heavier-duty type of gang switch would be more desirable.

The top row of buttons is used to operate the video switcher. The pressing of any one of these buttons will automatically switch the incoming signal from that particular camera to an extra, or 15th, monitor. Pressing the button to the far right will set the video switcher into automatic operation. These functions are explained under discussion of the video switcher. The two speakers located in the panel were designed to allow radio communication with any one of the camera enclosures. A buzzer is located in each cabinet, and by pressing one of the buttons on the control panel, the buzzer can be rung to attract the attention of a maintenance man working in the area. By plugging in his sound-powered earphones, he can communicate with the control center. This system has worked off and on, and while it is working, has proven to be very desirable. For some reason, there is still some hum in the lines, due to the combination of sound-power telephones and amplifiers. This, too, was such a minor part of the over-all system that it received little or no attention during the installation.

Video Switcher

A video switcher (Fig. 18) was included in the specifications and installed in the control center. As pointed out earlier, it allows an operator to select the incoming video signal from a particular camera and switch it to an extra, or 15th, monitor. This switch can be made in the event of the failure of any one of the monitors, or for study purposes. A study group can move this monitor to any location in the control center and study the output of any one of the cameras without interfering with the normal operation. This feature has proven very desirable and has been used many times.

Besides being used to study a particular traffic problem, the monitor is located near the counting and detector computer panels and allows an operator to check the efficiency of the counting equipment. A camera can be selected which actually shows the vehicles passing under a particular detector so that the accuracy of the computer equipment can be observed directly. This feature alone has proved invaluable many times in checking and comparing various counting equipment. The ability to switch an incoming video picture to an outgoing circuit has also been used to transmit a particular picture through the Bell system to another location. On two different occasions, a picture was transmitted to downtown Detroit over 4 mi away.

A second feature of the video switcher used in the control center is the ability to switch automatically from one incoming camera signal to another sequentially at a fixed time rate. This switching is motor-driven and can be adjusted for different time intervals. At the time of installation, there was considerable conjecture as to the need of a spearate monitor for each location. Most of the previous plans for traffic surveillance were on the basis that a man can only watch one monitor and that the incoming signal could be switched from camera to camera and provide the necessary control. Another reason for considering such type of operation has been in the cost of installation. Considerable savings can be obtained by switching one camera at a time. It would be necessary to have only one cable run the entire length of the system and the switching would be accomplished in the field at the camera. This would reduce the cost of the transmission considerably, especially if the distances were great.

At the time the specifications were written, no company would guarantee to provide a switching operation in which the successive pictures would form on the monitor without flip-flop. Because each of the cameras has its own synchronizing generator, the different pictures received from the different cameras would actually not be perfectly in step unless some master synchronizing signal was transmitted to each camera. This type of synchronization is complex and very costly and was not considered necessary because the decision was made to use individual monitors for each camera.

Several research studies that were programed would not be possible without individual monitors for each camera location. The securing of vehicle travel information through the study area was not possible with sequential viewing, nor does it lend itself to following happenings covering several camera views, such as stoppage waves. In

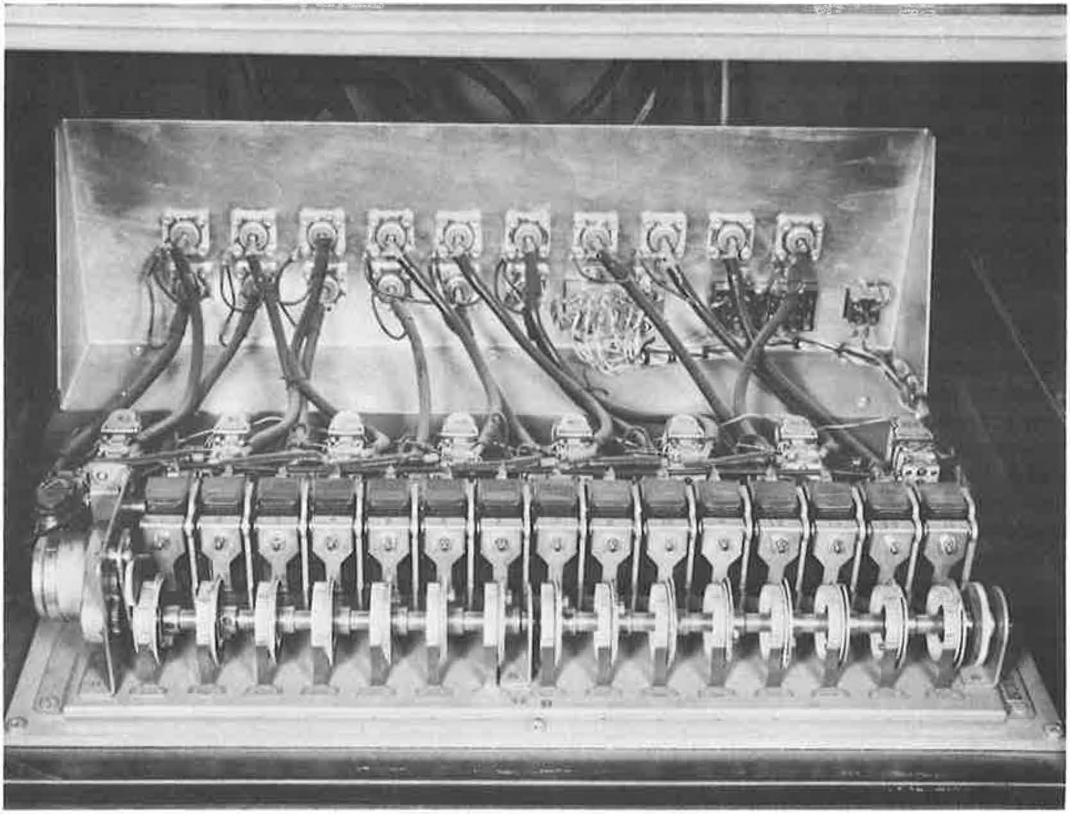


Figure 18. Video switcher.

actual practice, it has been found that the sequential switching operation is very satisfactory with the present camera and monitor. Most of the success is due to the very good synchronizing ability of the monitors used. The monitor is capable of synchronizing itself immediately to any incoming signal and the resultant change between pictures does not have any roll or flip-flop. This feature has amazed nearly every television engineer that has seen it operate.

Although experience has shown that the bank of monitors (one per camera) is very superior to the sequential method, the possible difference in installation cost will still require that a study be performed to find the limitations of a sequential system.

MONITORS

A monitor is the closed-circuit equivalent to a television receiver. In general, it has the same circuits as a television receiver without the tuning or sound systems. It does not necessarily mean that it is more economical because the synchronizing circuits and oscillator circuits are more refined and stable. Actually, this monitor has about the same tubes as the commercial television sets, irrespective of their additional circuits. The cost of the monitor is about $400.

The closed-circuit television buyer has a large range of monitors available. There is a choice among 8-, 14-, and 17-in. screens in the higher-quality monitors. Generally, the most used are either the 14- or 17-in. sizes. The 8-in. size is used for portable operation at a camera site for maintenance purposes. Although the 14-in. monitors could be mounted in certain conditions more closely together, the normal mounting is in the standard 19-in. radio racks. These racks are commercially available from several manufacturers and provide a pleasing arrangement at a minimum of cost.

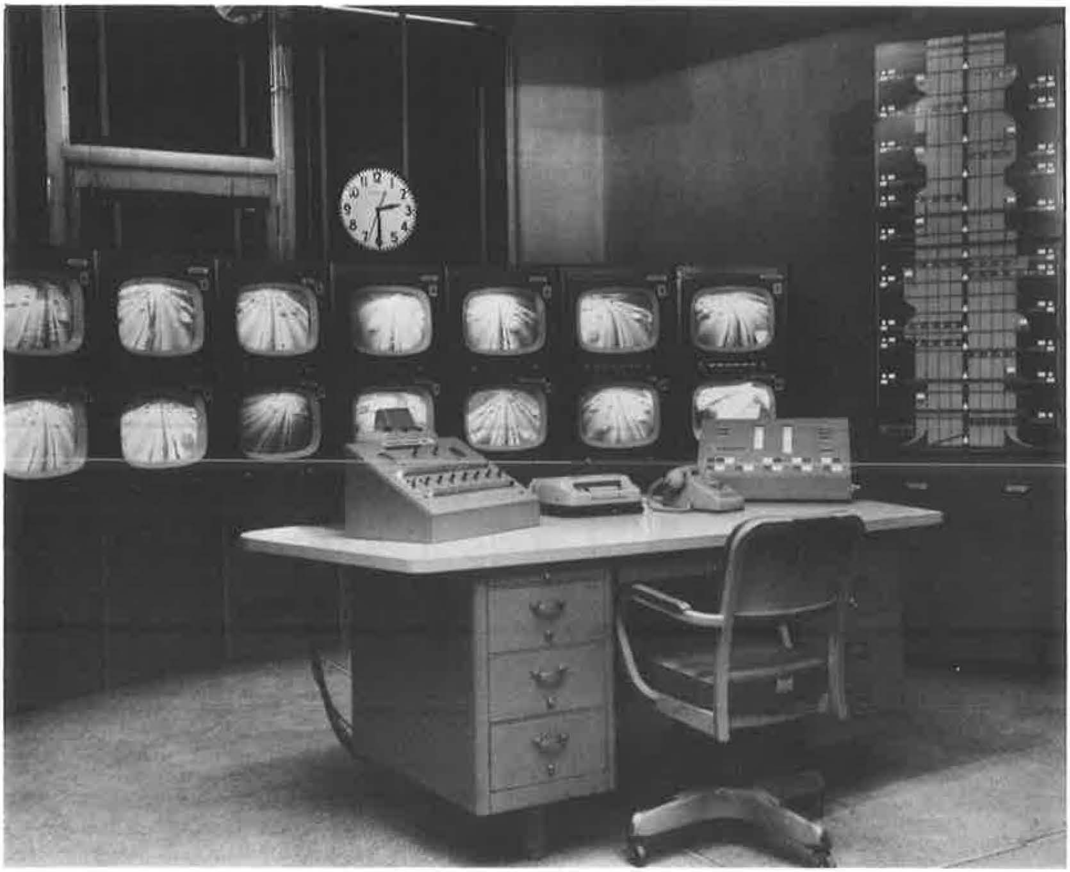


Figure 19. Control room, showing control, desk, bank of 14 monitors, and confirmation panel for signal control system.

Because these racks are of a standard size, the 17-in. monitor will fit in the same rack as a 14-in. monitor. This means that the spacing between the screens will actually be greater on the 14-in. size, and for general application, the 17-in. monitor would be the best buy.

Special 21-in. monitors are also available but are generally for classroom use and will not fit in the standard radio racks. Generally, the 21-in. monitors are not of the same high-quality design as that available in the 14- or 17-in. The monitor used for this project was a new development, and was by far the best monitor seen in operation (Figs. 19 and 20).

As stated under the section on random and positive interlace, one of the major problems noted in many monitors was a tendency to pair subsequent sweeps and therefore nullify the advantage of interlace sweeping. This monitor was never troubled with pairing or synchronization problems of any sort. As also noted under the section on video switcher, this monitor is capable of operating under sequential programing with present connections without flicker, roll, or flip-flop.

TRANSMISSION SYSTEMS

Another major item which seldom fails to receive proper attention in the original planning stages by the design engineers is the transmission facilities. The technical differences between four different systems that may be purchased and installed by the buyer or leased from various companies are discussed.

Figure 20. Freeway traffic as seen on television monitor.

Balanced-Line Video Cable

The term "balanced-line" refers to the cable construction. The cable consists of two conductors twisted together and enclosed in layers of shielding and weatherproof coverings. Balanced-line video cable eliminates much of the noise which is normally obtained on long-line coaxial cable runs. Noise pickup that would appear in audio systems as static appears in a video picture as white flecks or spots. Any amount of noise will materially reduce the resolution of the final picture. The balanced-line video pair automatically provides suppression of noise generated between the line and shield. Any noise picked up along the cable provides the same positive to negative ratio between the two conductors. Because the two types of signals are developed in different ways, specially designed amplifiers have no trouble sorting the noise from the actual video signal. Balanced-line cable costs about the same as high-quality coaxial cable and because of its automatic noise-limiting characteristics is superior for direct video communication.

The use of balanced-line transmission facilities is new in closed-circuit television. At the time the specifications were written, only one of the TV manufacturers was even proposing the use of this type of cable. The telephone company had been using balanced-line transmission facilities for short distances but with a lower band width than this project required. When the specifications were written, only one company could supply an amplifier that could amplify balanced-line transmission with a full 8-megacycle bandpass. By the time the contract had reached the letting stage, most of the manufacturers were starting to recognize the advantages of this system.

The longest transmission line is 10,000 ft and is producing high-resolution picture with no noticeable noise. The telephone company has transmitted the video for 4 ½ mi over parallel lines and again no problems occurred. Because a separate cable is necessary for each video chain and an amplifier is necessary for each mile, radio frequency modulation or microwave transmission will be more economical over longer distances. In the control project area, the control center is centrally located and most cable runs were short enough so that direct connections by the balanced-line video

cable not only provided the best picture but also was one of the most economical methods.

Coaxial Cable

The use of coaxial cable for the use of transmission of any high-frequency signal has been in general use for years. It is available in many sizes. The relative difference among coaxial cables lies in their attenuation or signal loss characteristics. The larger the cable is in diameter, the lower its losses in transmission. Naturally, the larger the cable, the more costly it becomes. The use of coaxial cable has been a standard by the closed-circuit television industry and at the time the specifications were written was in general use by most of the manufacturers. Generally, the manufacturers' experiences with long-line transmission were not too great. Very few of them had installed any systems over a mile in length. None of them wanted to guarantee a 10,000-ft chain with low noise levels. The coaxial cable has the disadvantage that all noise picked up from the shield develops the same positive to negative ratio of signal level with the center conductor as the signal itself. This means that it becomes difficult to retain a good signal to noise ratio. Certain suppression circuits have been perfected which sample the noise on the shield of the cable, amplify this noise, and run it out of phase on the signal cable. The balanced-line pair automatically provides this suppression.

Radio Frequency Modulation

A third method of transmitting video information from a camera to a monitor would involve the use of radio frequency modulation. A special modulation device is installed at each camera, and the output of each camera modulates a different radio frequency. These frequencies then are transmitted down the same high-grade coaxial line to the control center.

Demodulation equipment in the control center again sorts the signals apart and provides video to each respective monitor. The advantage of this system is that only one high-grade coaxial cable needs to be run to serve several video channels. With the 8-megacycle band width required, one company guaranteed the installation to transmit seven different signals over the same cable. In this case, they would use a very high-grade coaxial cable costing approximately twice that used for balanced-line video.

A manufacturer claims to have operated this modulation system over many miles of closed-circuit television. This method should certainly be considered where the length of the transmission would justify the savings in cable. Because a modulator and demodulator are necessary for each chain involved, the additional cost of $1,000 per chain would only be offset if a considerable distance was involved. The distance would be approximately 2 mi.

It could well be that if an expanded system were installed, the control centers of a maximum size would operate a certain area of freeway and a central control center would be interconnected with each local control center by one cable. The use of modulating equipment would allow several signals to be sent to the central control and provide the over-all intelligence necessary for an entire city. If it is determined that it is possible to get along with less resolution, or in other words a smaller bandpass, it is possible that 13 channels could be placed on one cable, as claimed by one manufacturer. Modulated signals on coaxial cable will still have to be amplified about every mile; however, the companies have developed wideband amplifiers that can amplify all channels at the same time.

Microwave Transmission

A fourth method of transmitting video information is by the use of microwave equipment. This method, of course, is being used for all broadcast work where long-range transmission is required. The cost of the equipment for each channel is approximately $10,000 and would make the transmission over short distances prohibitive. Again, the possibility of using such a system to transmit from a small control center to a master control center certainly could justify such equipment. There is a limitation in the

number of channels that will be approved by the FCC for this type of operation, which means that it did not lend itself too well to the transmitting of an entire facility simultaneously. It can be very economical for long-range transmission in that no intermediate amplifiers are necessary as long as the transmitting and receiving antennas are in sight of each other. When these antennas are located on small towers, the distance transmitted can be several miles. Microwave transmission also lends itself for portable set-ups. Small microwave transmitters are available which can be moved to a location in a reasonably short period of time and connected to a camera, so that a camera can be installed and connected to a control center in one day, if necessary. In a large, complex system, such equipment would provide good auxiliary facilities.

Cable Location

A completed freeway does not easily lend itself to the installation of additional cables. All lines on surface streets are generally 700 ft from the freeway and although the aerial runs on the pole lines can be accomplished economically, the laterals into each bridge can cost nearly as much as a cable run along the freeway by other means. Directly burying the cable along the sides of the freeway involves either tearing up the blacktop shoulders or cutting into the sodded backslope. Though either case is possible, it still involves costly runs beneath the entrance and exit ramps. The John C. Lodge Freeway has a continuous, raised median throughout the length of the project. This median has a guardrail down the center and is covered with bituminous concrete. Because the cameras were installed on the center of bridges crossing the freeway and directly over the median, the least costly location for the installation of this cable was directly along the median on the surface and attached to the guardrail posts. Because the duration of the project was originally set at only two years, it was not possible to justify spending money for a permanent cable installation, and this location was finally chosen because it was by far the most economical location.

The Michigan Bell Telephone Company submitted a bid for leasing the lines at a very favorable cost. Cost forced the installation of the cable on the surface of the median attached to the guardrail. They had each group of cables specially constructed into one large cable with an extra heavy polyvinyl sheet. An additional feature which was not specified was added. The cable was pressurized with 9 lb of dry air to keep out moisture.

Although the original duration of the project would allow no other installation, it now appears that a better location would have been justified. Considerable trouble was required to eliminate all leaks in the cable. Damage has been inflicted by vehicles on several different occasions. It appears that the most economical location for this cable would be to install it in duct under the median. The removal of the bituminous concrete would not be costly if a special chipper could be used and the duct work would not have had to be very deep under the surface for protection.

Conclusions

This report has not been written to provide specifications for a typical closed-circuit television system. Specifications would have to be written to consider all factors and conditions for an individual installation. This report has outlined the problems encountered on the John C. Lodge project and justified the reasons for the decisions taken.

There are several items remaining to be studied regarding the use of television for traffic control. This includes the feasibility of sequential operations for reviewing traffic, new and better methods of recording the information from the television picture, and determining the best location for camera sites to improve over-all visibility of the freeway.

The use of television for traffic work is still in its embryo state. The problem does not seem to be how good it is, but rather how much can be done with it. Its uses for study and control operation are practically limitless. Simultaneous viewing of long sections of the freeway can now be accomplished by one person, under all types of weather conditions at all times. Though this is possible over short periods of time from a helicopter, it is possible to watch more areas at once with better detail from television. The

location of a central site also makes it possible to install control facilities to change speeds and control lane usage. It allows the installation of detection devices that will record and tell the operator the exact volume and speed conditions of the traffic at the time he is watching it. The relation of all of these things has been nearly impossible until this time. The facility presently used on the John C. Lodge Freeway is probably one of the finest traffic research tools yet developed and project personnel can only be enthusiastic of the operation of this system.

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Appendix A

DEFINITIONS OF TERMS

Resolution. — The ability of a television system to distinguish fine detail in the subject matter.

Definition. — A term used to describe the appearance of sharpness or of being in focus.

Contrast Range. — The ratio of lightest to darkest light level.

Scanning. — Circuitry whereby a beam of electrons scans or sweeps across the image on the camera pickup tube and in effect, divides the image into narrow horizontal strips called lines. These lines are reassembled on the face of the monitor picture tube to produce the image. For each complete picture 525 lines are scanned in present television systems.

Field. — Each group of one half (262 ½) of the 525 scanning lines required to produce a picture.

Frame. — Complete group (525) of scanning lines, also called a roster.

Interlaced Scanning. — The scanning beam sweeps the image (down only) in 262 ½ lines and returns to the top. It then scans the picture again but this second set of lines are interlaced between the first set of lines. For each complete picture, 525 lines are scanned. Because 30 frames are scanned per second, $525 \times 30 =$ 15,750 lines each second.

Non-Interlaced Scanning. — When the beam scans the image horizontally and it reaches the bottom, it returns to the top and the scanning process is repeated. Random interlace occurs when the lines of the second field may fall at random anywhere between the lines of the first field and in some cases on the lines of the first field. If this occurs, it is called "pairing."