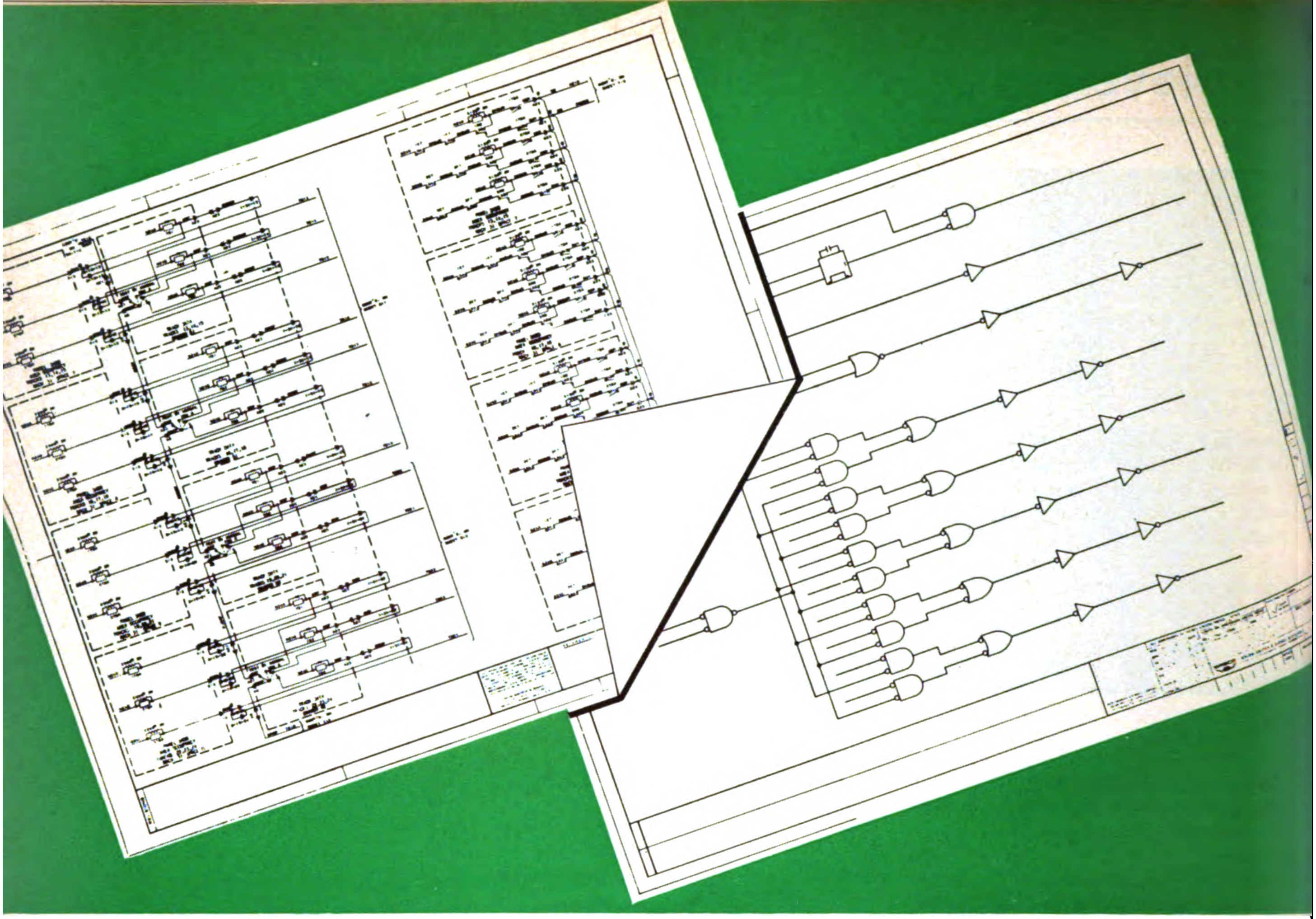


Computer vs Relay: Logic diagram for a computer (right) is equivalent to the circuit diagram for a relay system (left).

SIGNALING CONCEPTS

How computers may be applied

By W. P. Bollinger
Vice-President, Research & Engineering
Union Switch & Signal division WABCO

The history of railroad traffic control systems has been one of ever-increasing sophistication for the purpose of obtaining higher and higher work capability from the railroad capital investment. In applying newer technologies we are looking for increased capability to perform more sophisticated control and decision making functions; a flexibility not only to take care of the day by day operational variations, but also the foreseeable changes that are likely to occur in the basic railroad configuration and operating procedures. Of course, we are interested in getting these improvements at a minimum cost.

Let us look at the areas where we might apply computer technology to our railroad traffic control problems. Since a computer is basically a device which performs logical operations, any system which has as its primary purpose decision making on a logical basis with inputs and outputs which can be expressed as binary; that is, on-off or yes-no functions, is a likely candidate. Consider a relay logic system for the control of switching in a classification yard. Although this is a relatively small task for a computer when it is combined with other tasks in a classification yard, a computer may be attractive. Another possibility which has even more potential is the application of a computer to a centralized traffic control system, particularly where such a system involves rather sophisticated logic and decision making as might be required for automatic route selection and automatic train dispatching. Both of these examples involve a large amount of decision making based upon a pre-determined logic which is basically what a computer is designed to do.

Before we get into specific applications, let us first examine what a relay system basically does and what the electronic (usually solid state) equivalent of a relay system is. We are all familiar with the use of conventional relays in rather complex circuitry to perform various degrees of logical decision making. These relays have evolved over the years into very specialized devices for railroad applications which provide a large number of transfer points and the very high reliability required in railroad circuitry. If we examine these circuits (Fig. 1), we will find that regardless of the complexity of a circuit, it is basically made up of the two elements shown here. The first is a multiple circuit in which the relay contacts are connected in parallel. This circuit does the following: If either A or B is energized we will get continuity from C. The second basic circuit is our familiar series circuit in which the contacts are placed in series. For this circuit we can state if A and B are energized then we will get an output at C. Regardless of the complexity of the system, it is made up of these two basic elements.

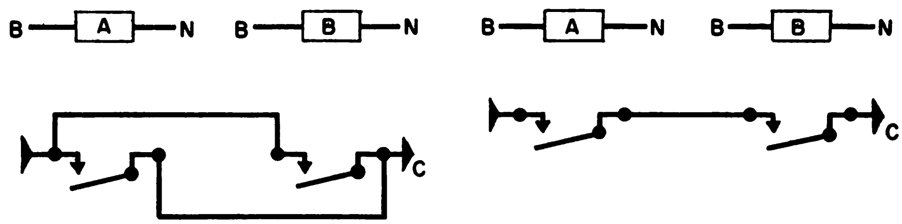


Fig. 1: Relay operation shows multiple circuit at left. If: A or B then C. The series circuit is at the right. If: A and B then C.

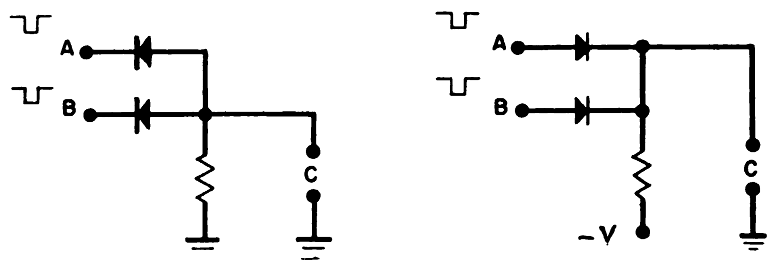


Fig. 2: Electronic equivalent of a relay circuit. Multiple circuit at left. If: A or B then C. The series circuit is at right. If: A and B then C.

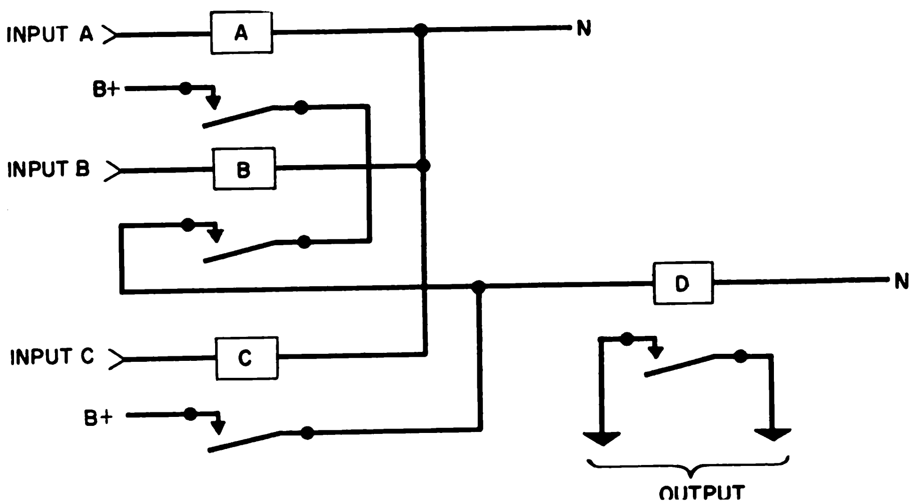


Fig. 3: Circuit will provide an output at the contacts indicated if either A and B is energized simultaneously or if C alone is energized.

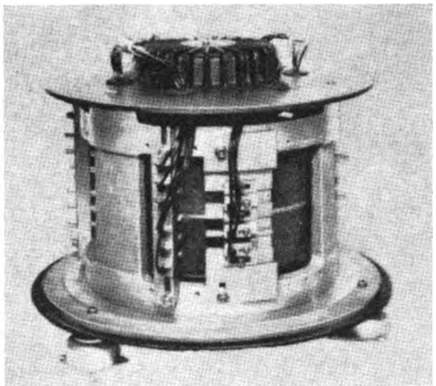
There is an exact equivalent of these basic circuits using electronic components rather than the electro-mechanical relay. In today's technology this is usually done with transistor circuits rather than vacuum tubes. The circuits for accomplishing these basic or/and functions are made up (Fig. 2) of diodes and resistors with transistor amplifiers if required. If a negative voltage is applied to either A or B, then an output will be obtained at C since such a negative voltage will go through either diode and provide a drop across the resistor. In the second circuit the diodes are reversed and a bias —V is provided. In this case the bias —V provides a current through the diodes until such time as both diodes are biased off. Therefore in this circuit if A and B are energized with a negative voltage, then a change in output will be evident at C. From this it is obvious that any relay circuit can be replaced by an equivalent electronic circuit to build up any degree of sophistication desired. By the combination of a number of relays we can accomplish a certain logical function; and by the combination of diodes, resistors, and transistors we can accomplish the identical function.

Now let us look at a concept which is probably not quite so familiar (Fig. 3). We have here a rather simple circuit which will provide an output at the contacts indicated if we either energize A and B simultaneously or if we energize C by itself. Now let us imagine for a moment that we had only one relay to carry out this logical function. We could envision placing this relay first in the position A and observe what it did by itself in the circuit. Its contacts would either be open or closed, depending upon whether we had input at A or did not have input. If we could now remember what happened to its contacts and lift the relay bodily from the position A and place it in position B, we could repeat the above analysis. Again, we must remember what happened to its contacts in this position. We now could put it in position C and again observe and remember what happened to its contacts. Likewise, if we took the same relay and moved it to position D, with the information we have remembered on the status of the contacts in its previous position, we could now determine what the relay would do in the circuit. So we can say that if we were able to move this one logic element, the relay, around the circuit and could remember what it did in each position, we might be able to get by with fewer relays.

To do this we need three important things: Suitable logic elements, a program the equivalent of the circuit diagram, and data storage for remembering what the element did in each position as we moved it around by the program. Both the program and the data storage basically require a memory system; and so from a hardware standpoint we need logic elements which are the basic and/or curcuits and memory which can be in a variety of types, the most applicable to railroad problems being magnetic cores and drums. The magnetic cores are used where high-speed operations are required within the computer and the magnetic drum is used for message data storage where access time is not quite as important. The drum is nothing more than the familiar tape recorder where the tape is now a rigid drum and the drum is of sufficient size that a large number of heads and recording tracks can be obtained.

In the discussion of how we might use a relay by rapidly moving it around the circuit diagram, it probably occurred to you that there are at least two reasons why this is impractical. The first is obviously the physical difficulty of moving a relay from one part of a circuit to another; and the second is that since we are performing the operations sequentially, the total time for completing the entire logic function is probably quite high. This is because it is accomplished serially with the relay delay time being multiplied by the number of positions it must occupy. The principles illustrated then must be accomplished with electronics rather than relays since the electronics can be moved around with the aid of other electronics and its speed of response is sufficiently high that the sequential operation does not create an impossible delay. We have now in very simple terms described what a computer does. It is nothing more than a device which performs logical operations by taking a small amount of fundamental logic elements and applies them in a sequential fashion by a pre-determined program with memory to record what is accomplished at each sequential step.

In order to understand what happens to a system as we change it from a relay system to an all-electronic system utilizing a computer, let us go through an evolution of a typical automatic route selection CTC and see how we might replace relay systems with electronic systems. This series of five steps (Fig. 4) will show such a progression starting with an all-relay system and finally concluding with an all-electronic computer system. The basic office system can be thought of in terms of functional blocks (top row). Coming from the code line we have a code system which has been indicated here as being "housekeeping", which is a term peculiar to the electronic designer but is equally applicable to our relay systems. The purpose of this functional block is to take the serial pulse code coming in from the code line and convert it to groups of parallel bits of information. This is equivalent to the US&S 514 system and others of similar capability. This grouping of bits in order to be useful is then delivered to a storage system, again consisting of relays. Upon the completion of transmission from all field stations, we would then have stored in these relays the entire status of the field. If we are going to have automatic decision making, such as is required for automatic route selection, we must have logic which again consists of relays. In an actual system the storage and the logic are very much intermixed with the same relay often performing both functions. However, as will be seen later, we need to separate these two functions to evolve into an all-electronic system. Lastly, in our functional block diagram, we have our control console which displays the status in the field and is now the input to a reversal of this flow of information to send controls in the field. The logic then performs certain routine functions for the dispatcher, with the non-routine decision making being accomplished by the dispatcher through the control console.



Magnetic memory drum may be used to store data or computer instructions.

As the system becomes larger and more complex, the speed of the relay system, particularly that part associated with the code system housekeeping, becomes limiting and it is necessary to provide coding speeds that are not possible with relays. It is now necessary (second row) to go to an electronic code system, which in principle performs the same function that the relay system did in the previous example. Just as in the relay case, the code housekeeping needs a storage for all of the information delivered in serial form and converted word by word into parallel form. Since the system is operating at a speed much higher than the reaction time of relays, it is necessary that this storage be electronic too. With the total information from the field now stored in the electronic storage, it is possible to go directly into the rest of the system via relays. However, now we must have a redundant storage in relay form since the electronic storage cannot directly drive the relay logic. From here on the system is identical to the one previously described. We can see, then, that the introduction of an electronic code system really requires a duplication of storage in order to interface electronics with relays. In fact, it has been necessary in some applications to have still additional relays to provide a transfer function from the electronic storage to the relay storage.

Now, since as we have previously shown, there is an equivalent electronic circuitry which will perform the basic logical functions of a relay, let us consider what would happen (third row) with the introduction of electronic logic rather than relay logic. Since we are now driving electronic equipment in the logic, we can dispense with the intermediate relay storage and eliminate this redundant function. At this stage of the evolution it becomes apparent that intermixed systems, electronic and relay, usually create redundant requirements and as a result are often uneconomical. We previously showed how the logic functions accomplished by electronics can be performed in another manner, namely the use of a smaller logic capability which is effectively moved around the circuit on a sequential basis to accomplish the desired result. We can therefore substitute (fourth row) this smaller logic with the associated memory for the larger logic of the previous example. Remembering that the memory system is nothing more than storage, we again have redundancy between the memory in the computer and the memory in the electronic storage. As a final step, this physical hardware utilized for electronic storage can be eliminated (bottom row), with all of the storage being accomplished in the memory of the computer. In its final form, then, we have greatly simplified the system by going to an electronic computer over the equivalent system using relays.

Let us look at what this means to the user. First, a relay installation for a rather small traffic control system occupies a rather substantial amount of space. A computer system for a rather large automatic route selection traffic control system is much smaller.

For purposes of further understanding how the use of a computer would affect you as a user, let us look at the comparative stages we must go through in the design and production of a typical system. The first step for a relay system is to prepare a circuit diagram. The equivalent of this for a computer is to prepare a logic diagram. The circuit diagram actually shows the connections of the electrical elements of the relays where the logic diagram shows the functional steps that must be accomplished in the computer. The next step is to prepare a wire list for the relay system. This is the information that is used by the wiremen to actually inter-connect the relays in the system. In a computer system a wire list is also required, but it is very much smaller because of the greatly reduced number of elements in the system. It also has the advantage that it is not unique to the particular application of the computer but is identical for installations of similar capacity. The variable part of the design starts with the preparation of the computer program which is a statement in computer language of the successive steps we wish the computer to go through to solve our total logic problem. When this program is completed it is put in a form which can be digested by the computer, for example, punched paper tape. It can also be placed on magnetic tape, punched card, or any other form of computer input. The last stage in the production of the final hardware is to wire the relay system or to feed the program, in this example, punched paper tape, into the computer. The information from this tape is stored in the computer memory and is equivalent to the electrical inter-connection of the relay system.

One of the principal advantages of the computer system over relays is its inherent flexibility. The logic that the system performs can be changed in a very short period of time with the introduction of a new program. To emphasize this point, we could take the extreme example of a railroad being completely changed so that its track plan bore no relationship to the previous track plan, but did have an identical number of indicator lights, levers, and pushbuttons. After the appropriate re-arrangement of these indicator lights, levers, and pushbuttons, the only other change that would be required to accommodate the new track layout would be a different program in punched paper tape or similar form fed into the machine.

Now let's take a look at comparative costs. A computer has the characteristics that in order to do anything it requires a complete complement of logic elements and memory. Unlike the relay system which tends to have a cost which is proportional to the size of the system, the computer system will start with a high initial cost and will have a more modest increase in cost with the growth of the size of the system. The growth with size is almost entirely made up of the cost

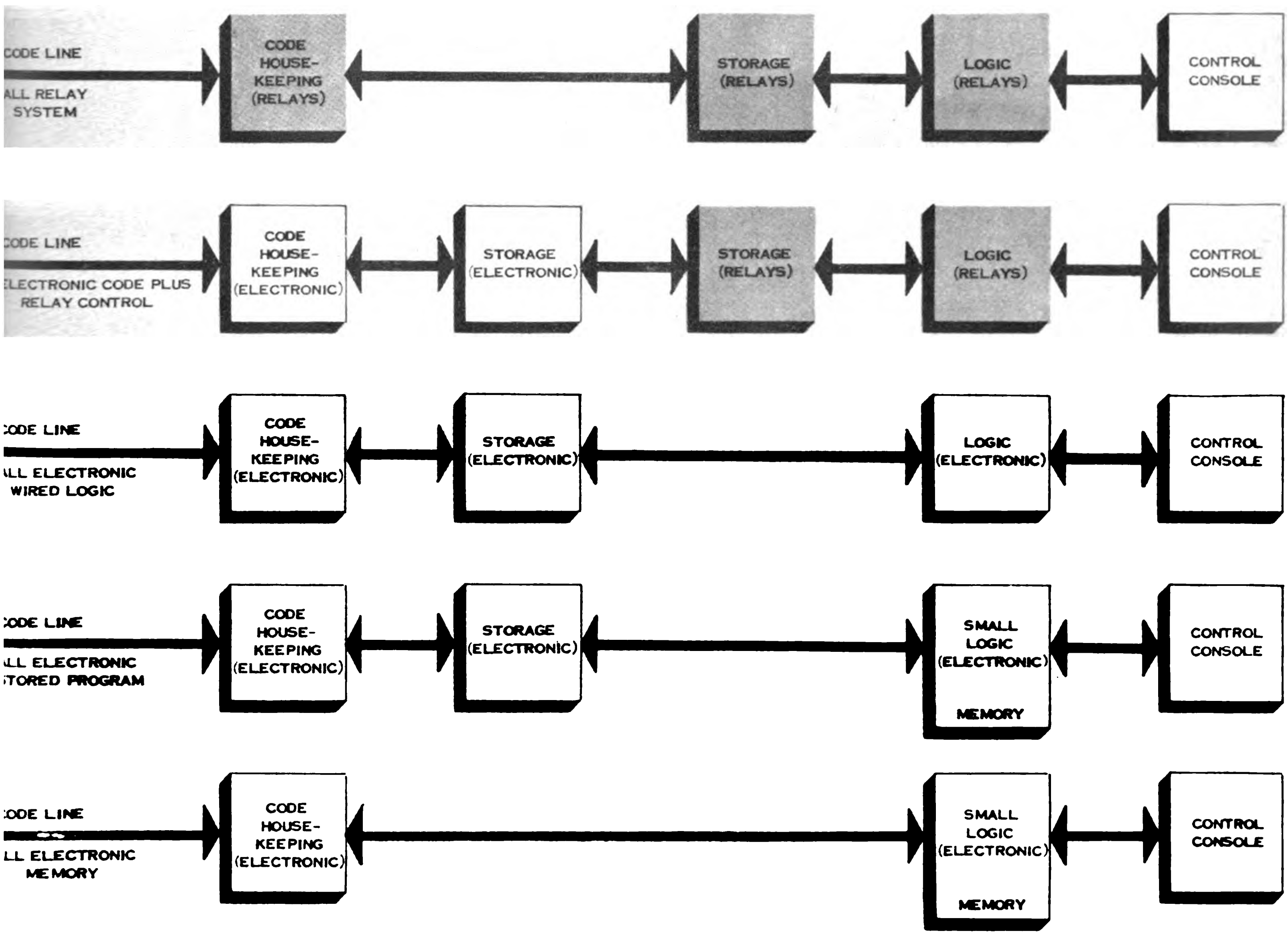


Fig. 4: How a relay system is replaced with an electronic system in automatic route selection CTC.

Computer and Relay Characteristics

	COMPUTERS	RELAYS
Cost Per Function	High—Simple Systems Low—Complex Systems	Moderate—Proportional to Size of System
Flexibility	New Programming via Punched or Magnetic Tape	Extensive Rewiring— Usually Added Equipment
Speed	Very High—Any Anticipated Requirement	Limited by Operating Time
Reliability	Potentially High—To be Proven for Railroads	Proven High by Experience
Maintenance	Fewer Elements but Requiring New Skills	Existing Trained Personnel Satisfactory
Space Requirements	Small Space for any Size System	Space Proportionate to System Size

of the increased components on the control console proper, with practically no increase in cost of the computer proper which performs the logic functions.

We can then summarize (above) the relative advantages and disadvantages of the two approaches by looking at each important feature. First, the cost. For a computer it will be relatively high for small uncomplicated systems but will be low for large complex systems. For relays the cost will be directly proportional to the size of the system. The flexibility of the computer system is very high, requiring only reprogramming and the introduction of this program into the computer. The relay system, on the other hand, requires extensive rewiring and usually the addition of equipment if new functions are to be performed. The speed of the system is very high for the electronic approach using computers and is limited by the operating time for electro-mechanical relays. If the system is not very large this is not a factor, but it does become a factor with large complex systems. The reliability of a computer system is very much unproven in railroad applications. Since the art is relatively new, we do not have the benefit of many years of experience. We can with some confidence look to its potentiality being very high in view of the tremendous effort on reliability stimulated by the aerospace industry, but for now we must say it is not proven. On the other hand, relays have many years of evolutionary development behind them and as a result have reached a very high state of perfection. We also of course have the benefit of many years of experience which gives us a high degree of confidence in their reliability. Fundamentally the maintenance of a computer should be easier since we have fewer elements, particularly in large systems. We must, of course, face the fact that few railroads are now manned for this type of technology, whereas the maintainers are well equipped to handle relay systems. The question, then, is one of training for electronic technology regardless of whether it is applied to computers or other systems, such as code systems. Finally, the space requirements are very small for a computer installation of fairly good size, whereas the relay system has a tendency to grow physically with its capacity.

There are applications for both systems. Certainly in a small system one would only consider relays. In certain situations the availability of trained personnel might also give preference to relays, but with the growing use of electronics in railroads this at best must be a temporary situation. On the other hand, if we wish to have more sophisticated and therefore more effective railroad control systems, the strong trend is toward computers. RS&C

Editor's Note: This is an abstract of the text of a paper delivered at the Communication & Signal Section, AAR, annual meeting on Oct. 27, 1964.