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An overall description of electronic weapon system maintenance training research which was conducted under Task FORECAST and which was directed primarily toward troubleshooting electronic systems is presented. This training research sought to determine the effectiveness of a method for analyzing electronic systems based on simple logic as opposed to the traditional method based on extensive electronic knowledge. Included in the report are previously unpublished research, assumed electronic-system characteristics, description of methods dealing with teat equipment and a contrast between training methods research and content research. Results of the several studies suggest that training based on FORECAST methods produces workers capable of effectively performing troubleshooting jobs with less training time than is required for traditional electronic maintenance training. (EM)

HumRRO

Research Report 13 May 1964

FORECAST Systems Analysis and Training Methods for Electronics Maintenance Training

by

Edgar L. Shriver, C. Dennis Fink,
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HUMAN RESOURCES RESEARCH OFFICE
operating under contract with

FORECAST Systems Analysis and Training Methods for Electronics Maintenance Training

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Task FORECAST

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During conduct of the research and preparation of this report Dr. Arthur J. Hoehn was Director of Research of the Training Methods Division. Before the report reached publication Dr. J. Daniel Lyons became the Division's Director of Research.

BRIEF

The present report is intended as an integrated, over-all description of the electronic weapon system research that has been conducted under Task FORECAST with emphasis on some new data concerning transfer and medium-fidelity part-task training equipment. This research has been directed primarily toward troubleshooting electronic systems. A principal feature of the approach, for both training and operational aspects of the various studies, has been to develop a method for analyzing electronic systems so that simple logic will prevail in troubleshooting them. When a system is analyzed and represented in FORECAST job aids, the repairman can respond to indications, or cues, and deduce their cause by troubleshooting logic rather than through his knowledge of the fine points of electronics theory.

FORECAST research findings bear upon three interconnected categories of questions:

(1) **Development of training content.** Under FORECAST methods, job demands are analyzed according to the cue-response paradigm to produce training content that (a) is based upon the kinds of information available about new weapon systems before they have been produced and (b) provides the information needed for effective job performance on the operational and maintenance tasks.

(2) **Development of training and job methods, aids, devices, and formats.** FORECAST work in this area has included such activities as (a) designing inexpensive, medium-fidelity mock-ups engineered for teaching FORECAST training content, (b) using surrogate or obsolete equipment to provide real-equipment training for new weapon systems, and (c) developing effective support products, such as troubleshooting block diagrams, from the equipment analysis.

(3) **Planning and management of personnel and training development subsystems.** FORECAST research has relevance to such aspects as (a) determining job demands and training content for new weapon systems before the equipment is available, (b) developing transition training to new weapon systems, (c) designing training for a multisystem Military Occupational Specialty, (d) increasing proficiency, (e) decreasing training time, and (f) providing training development methods that can be used effectively by expert Army electronics technicians.

This report draws upon several previous publications on specific phases of Task FORECAST but places somewhat greater emphasis on describing underlying rationale and theoretical concepts. It also describes some research, not previously reported, dealing with training methods and personnel subsystem problems.

A description of how the researchers viewed electronic-system characteristics in designing a troubleshooting process is given in Chapter 2, along with an example of the resulting process in operation. Application of the various concepts in the methods dealing with analyzing equipment is then described in detail in Chapter 3.

Some of the research that has been directed toward methods of training, in contrast to content, is described in Chapters 4 and 5. The studies dealt with training repairmen to acquire necessary troubleshooting skills and confidence, using equipment other than that of a new system in scarce supply. One study dealt with mock-up equipment that was designed to communicate the FORECAST type of information. The mock-ups were used as a substitute for operational equipment in portions of the practical exercises. Another study explored the degree to which a man trained in the content produced by the FORECAST method of system analysis can transfer his skills and knowledges to a weapon system other than that upon which he received his initial training, when both systems had been analyzed by FORECAST methods.

BRIEF

Conclusions and implications arising from the several phases of the research, and from initial experience in implementing the FORECAST approach in military settings, are presented in Chapter 6. They may be summarized as follows:

1. Training based upon the FORECAST type of equipment analysis results in effective job performance on both the operational and maintenance tasks in an electronic weapon system, with a decrease in training time.

2. FORECAST analysis techniques can be used successfully to develop the bulk of training content from the kinds of information available about new weapon systems before they are in production.

3. Analysis of electronic equipment by the FORECAST methods provides the basis for an effective troubleshooting process.

4. The FORECAST supporting documents, which represent a package of the results of the equipment analysis, fulfill the function of allowing rapid access to only relevant information for each troubleshooting situation. Among these products, which are applicable both in training and as job aids, are (a) a block diagram of the system, (b) narrative descriptions of the system signals which provide the basis for understanding sympton patterns, (c) identification and definition of dynamic signals at selected checkpoints, (d) schematic diagrams logically blocked for troubleshooting, and (e) a set of static tests for "within-block" checks.

5. The ability to use the FORECAST methods of system analysis can be taught to experienced, competent electronics technicians and can be applied by them to develop training content.

6. The results of the Mock-up study suggest that maintenance proficiency can be increased by the use of troubleshooting training devices. Students appear to learn some types of content more readily on mock-ups than on real equipment.

7. If such training devices are incorporated into the type of training employed in the Mock-up and Transfer studies, the requirement for costly equipment may be reduced.

8. In designing a training device, the developer needs to determine not only what skills and knowledges the training must impart but also how the device must be constructed to fit the training content. FORECAST studies suggest that an inexpensive medium-fidelity mock-up can be constructed to teach the application of conceptual activities such as in FORECAST troubleshooting methods.

9. The FORECAST approach can be applied to the problem of utilizing repairmen trained on one system after it has been modified by field changes or replaced by a newer system.

10. The results from the Transfer study suggest that the methods explored in FORECAST would also be applicable in training men to repair a number of different systems. Because skills developed in one complete training program include much that is needed for related programs, a method utilizing core FORECAST training in electronics maintenance, linked with a series of system-specific programs, could be used in producing multisystem competence in approximately the time now allotted to single-system training.

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FORECAST Systems Analysis and Training Methods for Electronics Maintenance Training

Chapter 1

THE RESEARCH PROBLEM

TASK FORECAST

In Task FORECAST the development of training was approached by means of analysis in terms of cues and responses—what the man perceives and what he does about it. The objective is to produce training content that (1) is based upon the kinds of information available about new weapon systems before they have been produced (such as schematic diagrams), and (2) will result in effective job performance on the operation and maintenance tasks in a man-machine system.

The purpose of the FORECAST analysis is to organize the system conceptually, so that a strict troubleshooting logic will hold throughout the system. This logic does not hold true in electronic systems unless such organization is accomplished. This point can be illustrated as follows. Consider a system like this:

$$\boxed{A} \longrightarrow \boxed{B} \longrightarrow \boxed{C} \longrightarrow \text{Output}$$

A simple troubleshooting logic is that a good input to C and a bad output from C means that the trouble is in C. In electronic systems, however, this is not necessarily true. Any repairman can show exceptions to this logic. Because of feedbacks, reflected troubles, "feelbacks," and other characteristics of electronic circuits, the trouble may well be in some other block. The traditional way of dealing with this situation is to try to give the repairman sufficient theoretical training in electronics to deduce and compute the exceptions.

The FORECAST research took another approach, that of analyzing the system so as to make the logic work without exceptions. When the analysis, called "cue response," is made by expert personnel using FORECAST guidelines, the simple troubleshooting logic does hold true. This allows a block diagram approach to be effective for actual troubleshooting rather than just for general explanations. Thus the repairman may respond to a cue as a straightforward and reliable indication of what troubleshooting procedure he should follow.

With the use of such methods, much training content development can predate the availability of operational equipment. Such anticipation can materially reduce the lag between the time at which equipment is first available and the existence of an effectively operating man-weapon system.

The development of training content based on the cue-response paradigm, and the evaluation of training based on the content for the operation and maintenance of the M33 Antiaircraft Fire Control System

are reported in HumRRO Technical Report 63.[1] The report includes a general description of the methods developed for analyzing electronic weapon systems in order to develop content for use in operator and maintenance training, and also in operational troubleshooting.

Analysis of the operator task was primarily a matter of identification and definition, since the system developers, in effect, build the operator's cues and required responses into the machine in the form of displays and controls.

For the maintenance task, however, a cue-response structure had to be imposed as a central part of the analysis. Essentially, the process involves developing guidelines for selecting and defining a system of highly efficient cues and responses from the large number available to the troubleshooter. Troubleshooting (identifying the cause of a malfunction) in electronic equipment is a process that involves, by interpretation of symptoms and measurements, successively eliminating from consideration those parts of the system that are not causing the trouble. Using the electronics information at his disposal (e.g., signal flow), the repairman makes a series of deductions which progressively narrows the source of the malfunction to one or more out-of-tolerance parts. Replacement or adjustment of these parts constitutes repair of the system.

An experimental 12-week electronics maintenance course, based on this approach, produced course graduates who were comparable in maintenance capability to those produced by the 30-week traditional training course. The cue-response approach appears, therefore, to provide an effective means for developing a training program supporting complex man-machine systems.

In the present report, the cue-response system is described and illustrated in some detail, with emphasis on presenting the underlying rationale and theory.

TRAINING METHOD IMPLICATIONS

Subsequent to research described in Technical Report 63,[2] and in contrast to the earlier emphasis on training content, certain aspects of the cue-response system have been evaluated and training methods investigated, in order to make most effective the training based on this system. This research is described and its theoretical and practical implications discussed in the present report.

The further developments of the cue-response paradigm in the more recent studies were in two directions. Firstly, there was a more detailed analysis in order to distinguish between the portions of training specific to a particular system or subsystem, and the portions with general applicability to other man-machine systems analyzed in the

[1] Edgar L. Shriver, *Determining Training Requirements for Electronic System Maintenance: Development and Test of a New Method of Skill and Knowledge Analysis* (Training Methods Division), Technical Report 63, Human Resources Research Office, Alexandria, Va. (published in Washington, D.C.), June 1960. See Appendix A of the present report for a summary of the above research.

[2] *Ibid.*

cue-response paradigm. That is, analysis attempted to distinguish, within the training program, between training content that is specific to the particular man-machine system or subsystem and training content that is specific to general electronics maintenance, and relatively independent of the particular equipment to which it is applied. The results of such analysis can be critical in estimating how readily graduates of a cue-response training program for one system can reach operational capability in transition training for related or new-generation man-machine systems of similar character.

Secondly, analysis of the training program from a somewhat different point of view suggested consideration of the training content as being composed of:

Decisional and interpretative skills that do not need to be learned on real equipment—operational skills such as energizing procedures and use of test equipment, recognition of various correct and incorrect indicators, relationships between symptoms and malfunction locations, troubleshooting logic and functional understanding of system areas.

Mechanical and familiarizing skills that need to be learned on real equipment but are not system-specific—for example, procedures for working with energized equipment, soldering skills, and the general process of becoming familiar or at ease working with high voltages.

Operational training dealing with system specifics and integration of knowledges and skills that can be conducted only on the subject system—for example, location of parts, and practice in an operational context.

The latter analysis can provide guidelines for determining (1) critical characteristics of training devices or mock-ups for use in training based on cues and responses, and (2) the possibilities, and the manner, of using obsolete or other equipment in advance training for a new system. Further, this analysis provides a basis for programming training—that is, determining how to sequence the various kinds of training content and deciding the optimum amount of training necessary on each kind.

STANDARD TROUBLESHOOTING TRAINING

Current troubleshooting training is based on the proposition that in order to troubleshoot a radar system, a repairman should have sufficient theoretical knowledge to compute the correct value at all the possible checkpoints in the system.[3] Corollary to this, he should know or be able to determine the parts of the system that affect the values at every point.

When the repairman, using simple measuring instruments, checks the system at various points while it is intact, the process is called system troubleshooting. When chassis are removed from the system, and energized and tested with special ordnance test equipment, the process is known as Ord 6 (or Type IV) troubleshooting. Since the Ord 6 primarily provides an alternative way of energizing the chassis

[3]The newer technical manuals include more data about checkpoint values, but the belief that a man should have enough theoretical information to determine the values is still strong.

in the same manner as the system energizes the chassis, there is considerable overlap in the knowledges required for the two types of troubleshooting.

Today, standard training for troubleshooters prescribes three types of electronics knowledge: general or basic electronics, system-specific electronics, and probability of electronic part-malfunction. In the first phase of training which is the basic electronics course, conducted by Signal Corps in the past, the student is provided with general electronics information, including general methods for computing theoretical values at any point in the circuits. He is also provided with some information on the probability of malfunction of various types of parts and some opportunity to practice applying his theoretical knowledge in selected practical exercises. From these knowledges the repairman is expected to draw the information required to determine, for any particular malfunction, which parts in the system are within tolerance and which are out of tolerance.

In any type of training that might be envisioned, as in today's training, the electronics repairman will need to acquire certain basic, general electronics information. With sufficiently long training, enough theoretical electronics presumably could be taught to increase troubleshooting efficiency over the level attained with the amount of training time allotted today. There is, however, a ceiling on the amount of improvement that can come with increases in theoretical knowledge, and that ceiling may be closely approached in current Army training programs. On the other hand, the ceiling on improvement can be raised by the type of information that bridges theory and practice.

Thus the content of the FORECAST experimental training represents a sharp increase in bridge-type information, and a decrease in theoretical information, with the emphasis placed on learning how to actually repair equipment.

Chapter 2

THE FORECAST APPROACH TO TROUBLESHOOTING

The objective in the maintenance task analysis was to describe and characterize electronic weapon systems at the level and in the detail required for an effective performance of the repairman's job. Certain characteristics of the electronic (radar) system were used in the FORECAST task analysis to develop the materials needed for rapid, accurate troubleshooting.

To provide a better understanding of how the method of maintenance was developed, these system characteristics as they were viewed by the research staff in designing a troubleshooting process are described briefly in this chapter. An explanation is also given of how the repairman uses the troubleshooting process which resulted from the FORECAST analysis.

ELECTRONIC SYSTEM CHARACTERISTICS

To accomplish rapid troubleshooting, certain patterns of relationships and independencies in the electronic system must be utilized. To the novice in electronics, major electronic weapon systems such as the M33 look like a mass of parts each of which seems to be related to every other. The task requires an organization of this mass of parts into a pattern that will be meaningful and effective for the performance of maintenance.

On any electronic system there are built-in displays such as radarscopes, voltmeters, and lights. These displays are the source of symptoms, which indicate the system is malfunctioning. The source of a malfunction can be localized to a certain area of the system by considering in combination the various symptoms or symptom patterns; for example, if there is no video on the radarscope, yet all voltages and all other aspects of the displays are correct, the trouble can be localized to those parts in the system that process video, on the video channel.

The various channels in the system can be further subdivided by measuring the signal at specific points along the course of the channel. These checkpoints are measured with portable test equipment (e.g., oscilloscope). The segment of the channel containing the malfunction is identified when the signal is found to be good at one point and bad at some checkpoint further on in the channel. By testing groups of parts in a bad segment with certain other portable test equipment (e.g., ohmmeter), a small group of parts and finally a single bad part can be identified.

A description follows of how these relationships and other key system characteristics were viewed for FORECAST maintenance purposes.

General relationships among components may be described in terms of signal flow. A signal starts from some type of signal generator and goes through a series of electronic parts which constitute a "channel" for the flow. Each component in the channel changes the signal slightly; therefore, the original signal is continually changed as it moves along its channel. There are many relatively independent channels in a system.

Most of the channels terminate on a portion of the equipment that makes the signal in the channel visible. They may end as a mark on a phosphorescent scope, or as a meter reading, or as a movement of an antenna. If a normal signal appears, it means that all components in that channel are functioning properly. An abnormal signal or absence of a signal is the symptom of malfunction.

Before the terminal point of a channel is reached, signals may be switched from one channel to another by operator controls. An alternate channel may have a different terminal point or may lead back to the original channel before the terminal point. In some instances, two channels may meet, resulting in a new signal, which travels in a new, third channel.

Visible signals appearing at the end of a channel on built-in indicators (equipment displays) are readily available to repairmen. The visible signals are efficient isolators of malfunctions because they contain information that allows a distinction to be made between parts in various channels. (E.g., by merely looking at the M33 track radar displays, the knowledgeable troubleshooter can eliminate about 96% of the possible malfunctioning parts from consideration.[1]) The fact that the abnormal signal is affected only by the parts in one channel and is independent of the parts in the other channels permits the troubleshooter to narrow the search. He has thus isolated the malfunction in general terms through a process that might be called "symptom-area identification."

Before the terminal point of the channel is reached, signals may be switched by means other than operator controls, that is, they can be made visible by sidetracking them from their channels with portable test equipment (voltmeter, oscilloscope, ammeter). The appearence of a signal on a test instrument indicates whether all portions of the channel leading to this sidetrack are functioning properly.

The sidetracking action of portable test equipment furnishes progressively more accurate identification of the malfunctioning area in a series of steps. The malfunctioning area or channel segment can first be isolated to a small number of parts (in the M33 system to less than 1% of the parts in the system). The two or three tubes and associated parts involved may be viewed as a "troubleshooting block," and

[1]Analysis of the M33 track subsystem resulted in isolation of about 24 channels. Selection of one channel from 24 would limit the possibilities to 1/24 or about 4% of the components in the subsystem. As all channels do not have the same number of parts in them, the figures used are averages.

the wave form that would be affected by a malfunction of any one of these parts can be used to isolate the malfunction to this block. This step may be called "block identification."

Within a troubleshooting block, the parts, such as resistors and capacitors, are related in a sequential manner. Most importantly, they are all attached to tube pins. A tube usually has seven or nine pins. Attached to each pin is a chain of from one to about six parts which, acting together, produce a certain resistance (or voltage) reading at the tube pin. The resistances of chains can be made visible and measured at the tube pins with portable test equipment (ohmmeter). Since the correct resistances are known for each pin, a measured change from the correct value indicates a malfunctioning part in the chain attached to that pin. This step may be called "tube-chain identification."

Once the malfunction is reduced to a short chain of parts, it is simple to locate the one part that is out of tolerance. This last step may be called "part identification." Each part has a resistance value which changes (generally to zero or to infinity) when the part malfunctions. Since the correct value for each part is known, a measured change from that value indicates a malfunction. If the circuit attached to the tube pin is such that the resistance will not change when a certain part malfunctions, parts that are "hidden" in the tube-pin circuits need to be tested individually.

To recapitulate, the steps in malfunction identification are:

Symptom to symptom area
Symptom area to troubleshooting block
Block to tube chain
Tube chain to individual part

A new chassis can be substituted for one assumed to contain the malfunctioning part; if the assumption was correct, the new chassis causes the equipment to function properly again. This is another characteristic of most electronic systems which can be utilized in troubleshooting, either independently or as an integral part of other methods. The system is made up of a number of chassis because of the physical convenience of handling several small pieces of equipment rather than a single large one. Chassis are connected to the rest of the system through pressure contacts, so that they may be removed from the equipment without the time-consuming unsoldering of connections.

The preceding material is not in itself new; maintenance men have been using these malfunction indications in their troubleshooting for years. However, a method had not been developed for systematically using a defined set of symptoms for a system of cue-and-response actions. The method of system analysis described in Chapter 3 of this report makes possible a simple, logical system of troubleshooting. End-of-channel information is used first because it is immediately available from inspection of built-in indicator displays and effectively discriminates between good and bad channels. Sidetracking action by portable test equipment is generally used next, as each measurement checks a large group of parts. In the final steps, relatively short chains of parts and individual parts within the chain are measured by resistance meters. This sequence results in an efficient troubleshooting

procedure which is easy to follow, highly reliable, and economical of troubleshooting time.

FORECAST TROUBLESHOOTING—AN ILLUSTRATION

FORECAST troubleshooting is not a procedure carried out mechanically "by the numbers," but certain information produced by electronics experts during the equipment analysis described in Chapter 3 is incorporated in the supportive documents that are a part of this troubleshooting process. Some of the information is of a nature that cannot be derived from theory. The documents include troubleshooting block diagrams, checkpoint sheets, schematics blocked to support piece-part troubleshooting, and resistance and voltage charts.

As a basis for the conceptual presentation in the next chapter, the following section provides a concrete example of how the repairman uses the FORECAST troubleshooting procedure:

(1) Since the repairman has been trained to recognize symptoms and patterns of symptoms, he recognizes an incorrect presentation on an A-scope. He makes his first check (identifying the symptom area) by looking at the presentation on the other two A-scopes to see whether they too are abnormal. In the example of the M33 tracking radar (Fig. 1), the tracking indicator is bad; the other A-scopes are good. From this pattern, the repairman decides that the trouble is in the bad A-scope itself rather than in circuitry that feeds all three scopes. The trouble

M33 Tracking Radar

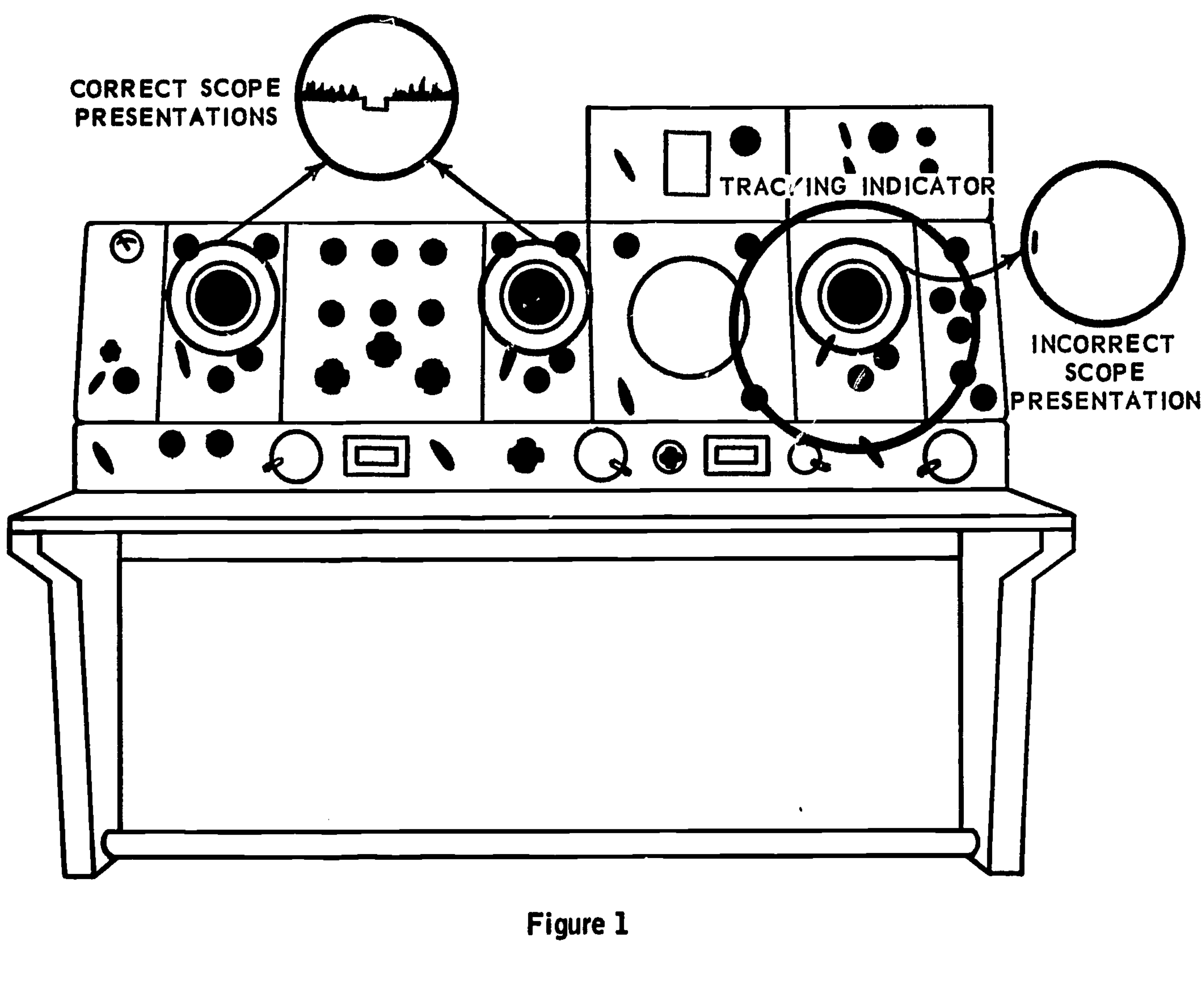


Figure 1

Tracking Indicator

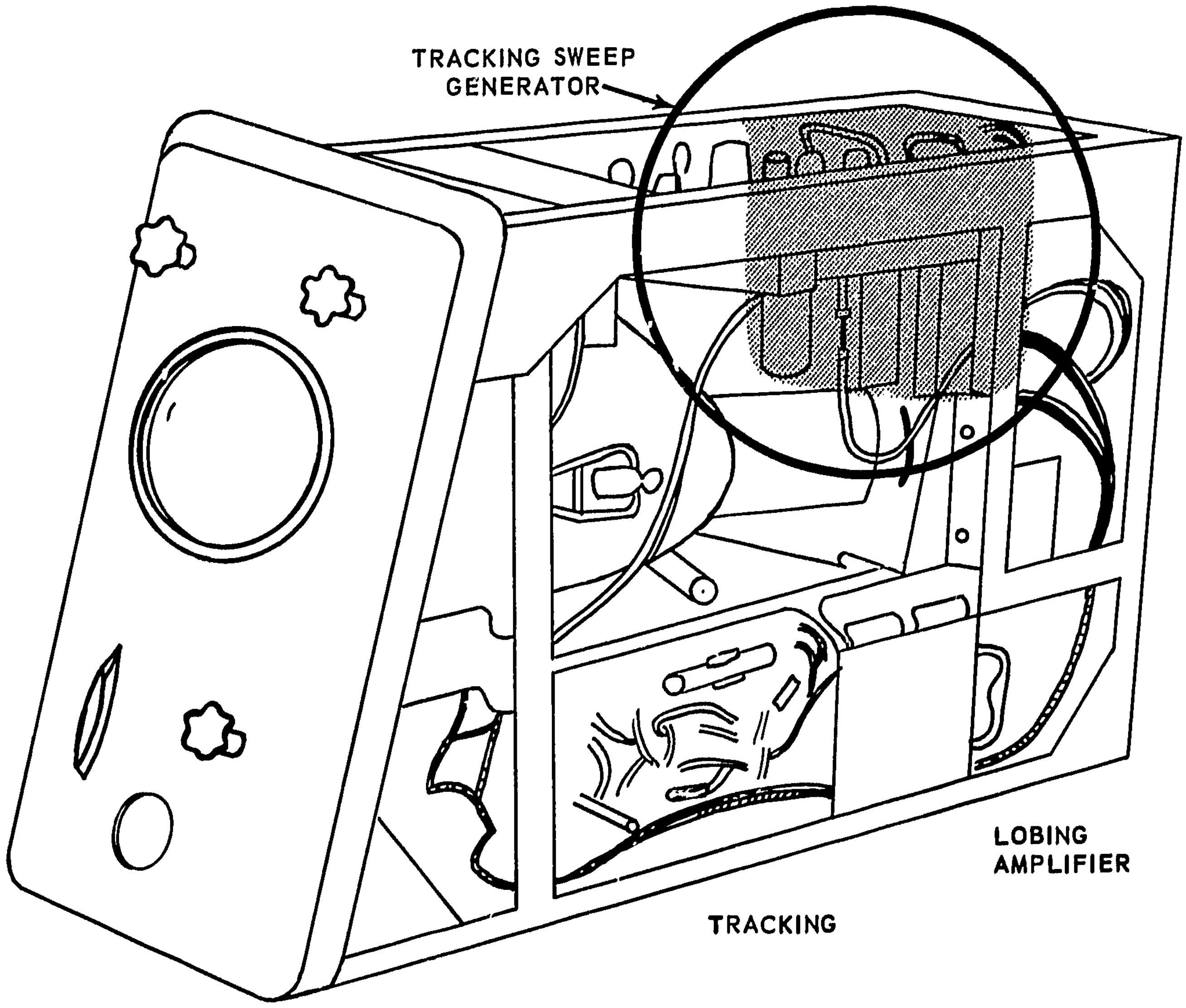


Figure 2

has now been localized to the area of one A-scope. This area is illustrated in Figure 2 and is outlined by the larger circle on the block diagram of the tracking subsystem (Fig. 3). This circle contains several chassis.

(2) The repairman notes that on the bad A-scope there is a vertical line that is not spread out horizontally. From this he deduces that the circuits driving the vertical plates are operating properly but that those driving the horizontal plates are not.

(3) He looks at the block diagram and selects the three blocks enclosed by the smaller circle on Figure 3 as the possible causes of this trouble. This is the area within the circle, marked "Tracking Sweep Generator" on the drawing of the tracking indicator (Fig. 2). These three blocks are selected because they feed the horizontal plates of the bad A-scope, but not those of the other two scopes.

(4) He notes the names of the blocks from the block diagram and finds these names on the checkpoint table. (See Fig. 4 for sample of checkpoint table for tracking indicator.) The places in the equipment at which to make the checks are listed in the table. All are within the largest area drawn on the photograph of the tracking sweep generator (Fig. 5); the repairman knows this because the tube numbers in the blocks are listed on the checkpoint sheet. He makes each check and compares the result with the output designated on the checkpoint table. By these

FORECAST M33 IFC Troubleshooting Block Diagram, Tracking Subsystem

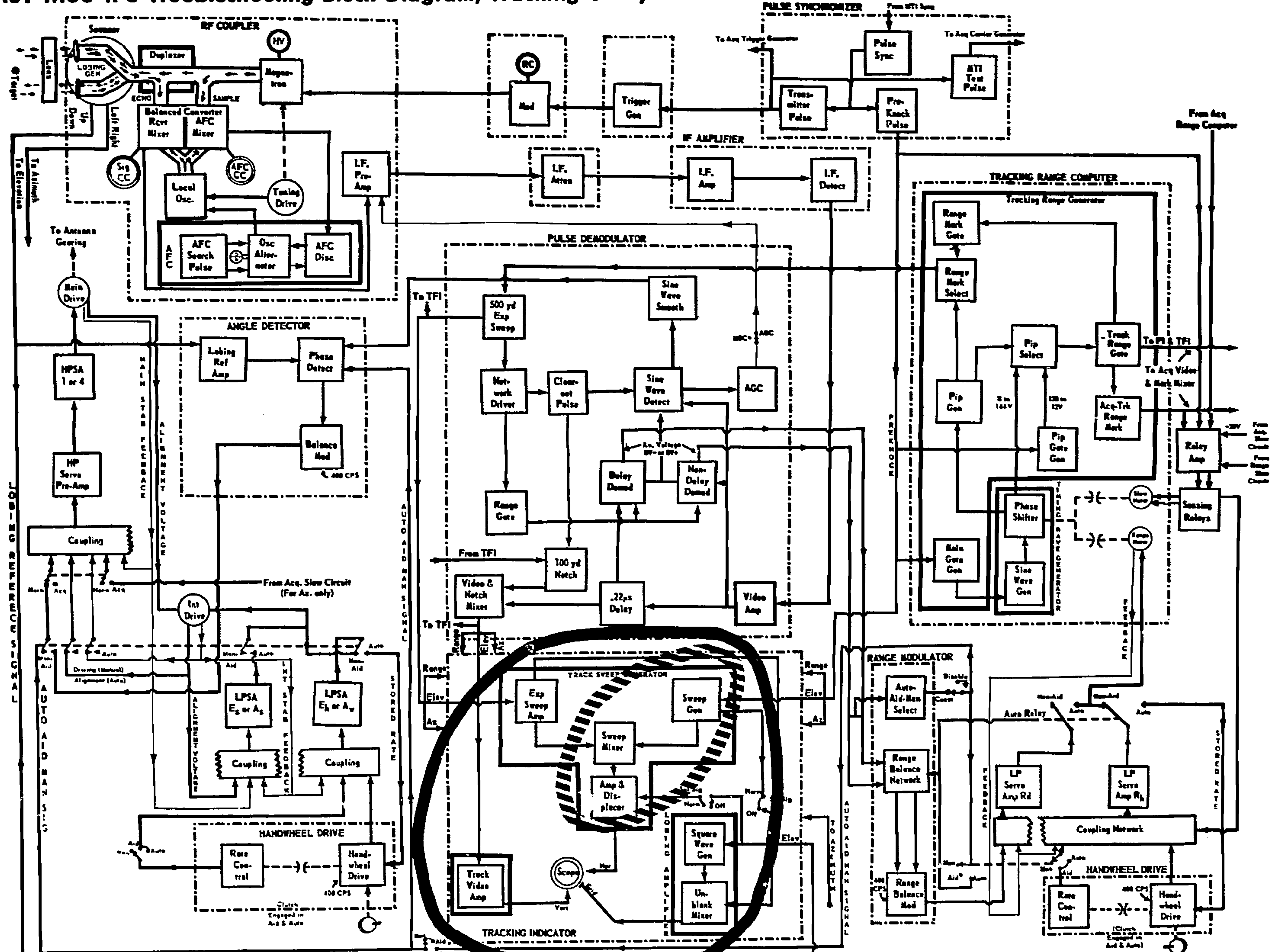


Figure 3

Sample of Checkpoint Table—Tracking Indicator

Blocks	Tube Numbers	Checkpoint	Wave Form
Sweep Generator to Sweep Mixer	V3 & V6	V3, pin 2	
Sweep Mixer to Amplifier and Displacer	V3 & V6	V4, pin 2	
Amplifier and Displacer to Scope	V4	E1: A and E1: B of Sweep Gen or V4, pins 1 and 9	(or reverse)

Figure 4

Tracking Sweep Generator

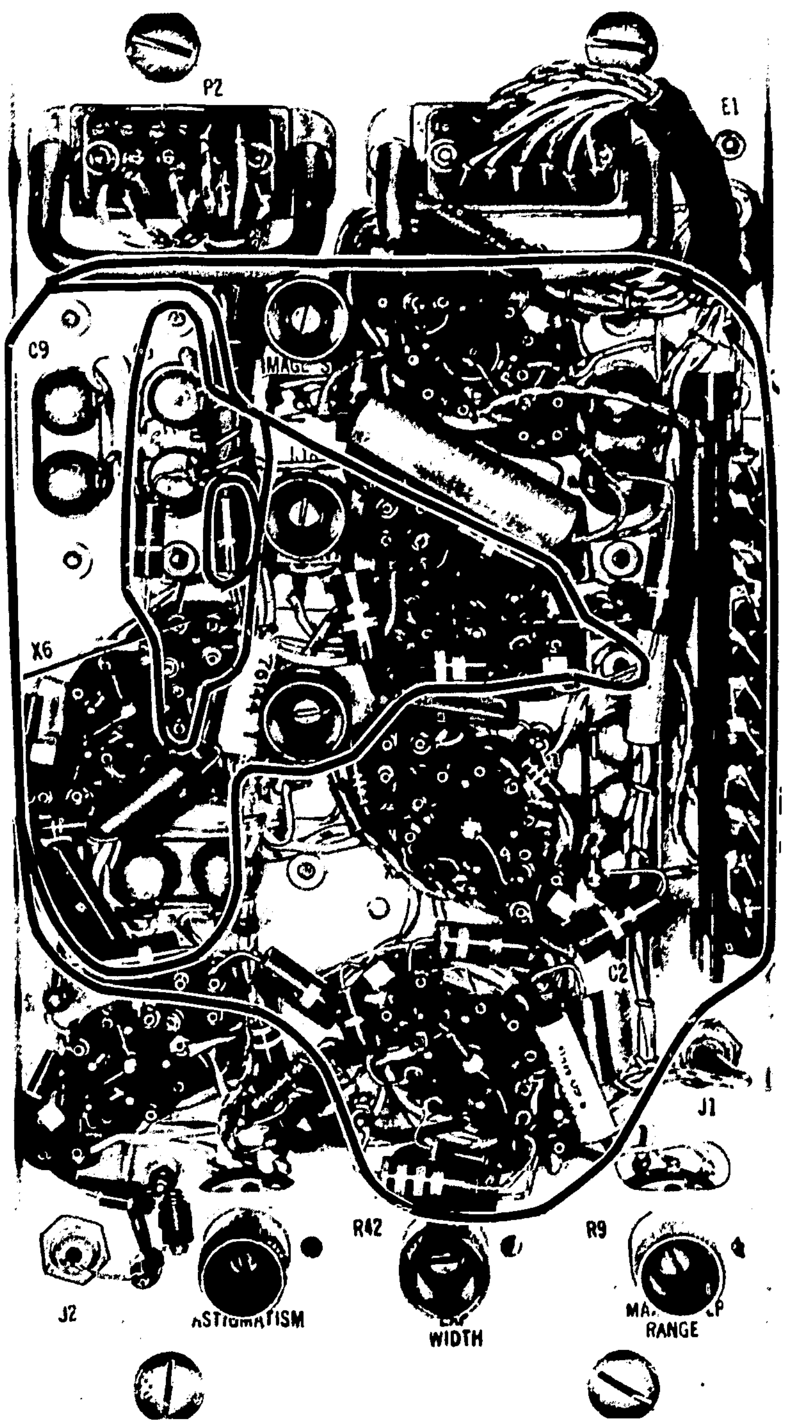


Figure 5

checks he identifies the malfunctioning block (the second largest area outlined on Fig. 5) as the one with a good input and a bad output.

(5) The repairman checks the tubes listed for this block and, if a bad tube is found, replaces it and verifies the repair.

(6) If no tube is found to be malfunctioning, he notes the name of the block and the chassis containing it, and consults the schematic diagram for that chassis. In the schematic diagram for the sweep mixer (Fig. 6), the piece-parts contained in the malfunctioning block are outlined by a heavy line; the same parts are enclosed in Figure 5 by the third largest outlined area. (Note: The piece-parts that will affect the output for each block have been determined and verified by system experts.)

(7) The repairman at this point determines that one of these piece-parts (capacitors, resistors, coils, etc., ranging from 3 to 30 in number) is bad. He removes the chassis containing these parts in order to measure their DC resistance.

(8) To make the resistance measurements, he attaches a test adapter to the chassis input-output plug which connects all inputs and outputs to ground. He uses an ohmmeter to measure the resistance between each tube pin and ground. The correct values for each tube pin in every electronic system are recorded in an Army technical manual covering the system, called a "Voltage and Resistance Guide" (see Fig. 7).

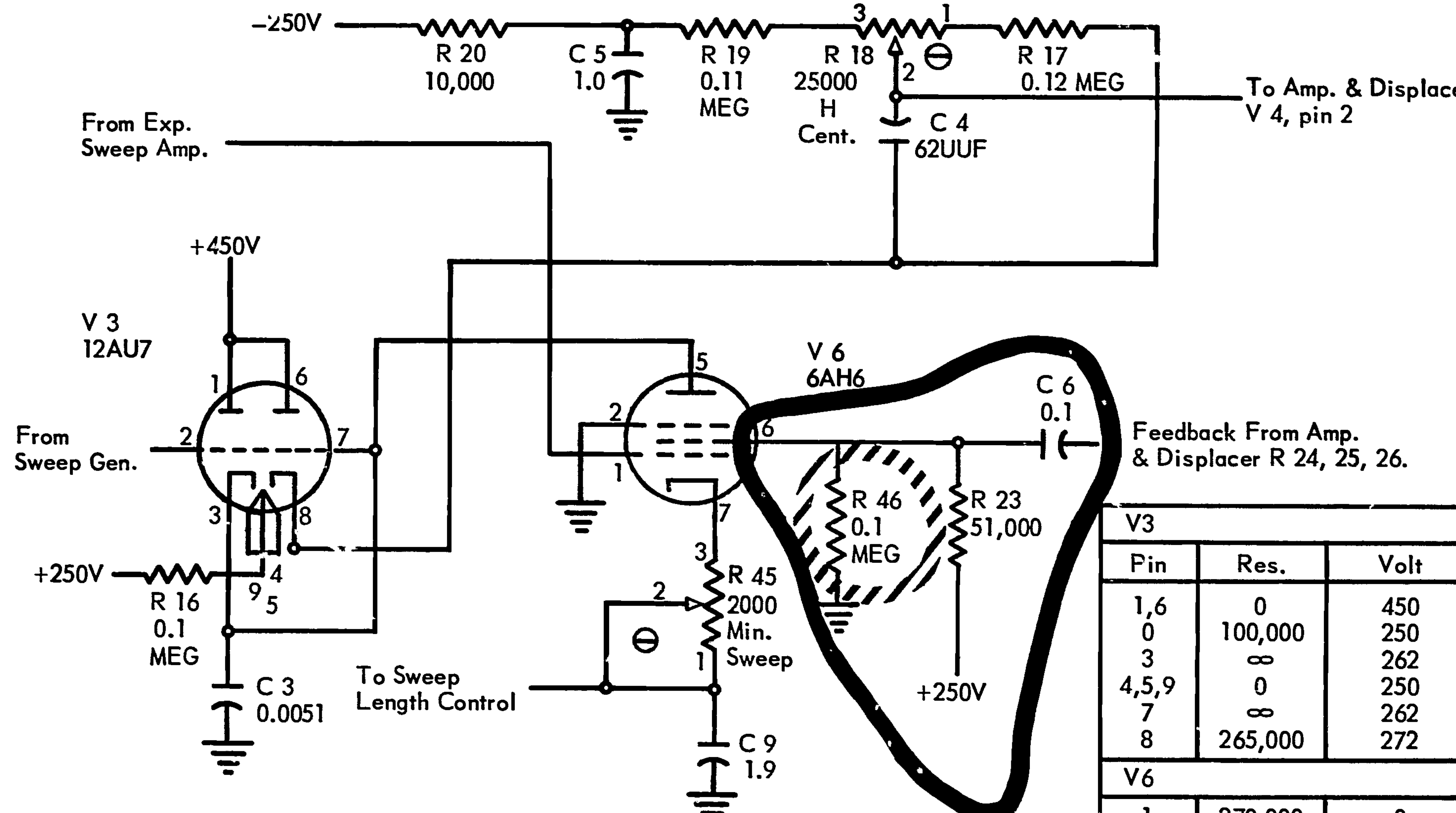
(9) When a resistance is found to be incorrect, the repairman knows that one of the parts attached between that pin and ground is bad. He measures each part attached to the pin to determine which one is causing the system malfunction. He replaces the bad part and verifies the repair by reinserting the part in the system or by testing in Ord 6 equipment. In this example, the faulty part is in the smallest area outlined in Figure 5.

(10) If he finds that resistance readings on all pins are good, he knows that the malfunctioning part is in a certain type of circuit, all of whose parts cannot be checked by resistance readings at tube pins. These "hidden parts" are found by examining the schematic diagrams to locate such circuits; examples are resistors in series with capacitors, and resistors in parallel with coils. He then measures the parts in such circuits individually (independently of their circuit) to identify the malfunctioning part.

(11) A type of malfunction that cannot be reliably identified with resistance measurements is an open capacitor or one that breaks down only under load. The repairman concludes that he has this unusual, and always difficult, problem when no other parts in the malfunctioning block are found to have incorrect resistance values. He must then test each capacitor in that block on a capacitor analyzer, or replace each one.

(12) If this process does not clear the malfunction, even an experienced repairman or engineer would be at a loss to explain the difficulty, and would probably be ready to try anything. The experienced repairman has an advantage here, not because of superior theoretical information but because he has in the past, tried desperate measures—wiggling wires, banging the chassis on the table, or pronouncing various curses on it—and sometimes found these irrational methods unexpectedly effective.

Schematic Diagram for Sweep Mixer



V3		
Pin	Res.	Volt
1,6	0	450
0	100,000	250
3	∞	262
4,5,9	0	250
7	∞	262
8	265,000	272
V6		
1	270,000	0
2	0	0
5	∞	262
6	33,000	154
7	1,300	4.8
3-4	>0	6.3 ac

Figure 6

Sample Page From Voltage and Resistance Guide—Tracking Sweep Generator Readings[a]

Socket No.	Tube No.	Tube Type	Tube Function	Plate			Suppressor			Screen			Control			Cathode			Filament		
				Pin	Volts	Res	Pin	Volts	Res	Pin	Volts	Res	Pin	Volts	Res	Pin	Volts	Res	Pin	Volts	Res
X1	V1	12AU7	Multivibrator	1 1 6	250 157	33,000 6,000							2 7	0 21	4,700 2.5 meg	3,8	21	1,500	4,5 to 9	6.3ac	>0
X2	V2	12AU7	Bias Diode	1	21	2.5 meg							2	21	2.5 meg	3	21	10,100	4,5 to 9	6.3ac	>0
			Cathode Follower	6	450	0							7	250	33,000	8	250	100,000	4,5 or 9	125	0
X3	V3	12AU7	Switch	1,6	450	0							2	250 260	100,000	3	262 270	-	4,5 to 9	6.3ac	>0
			Cathode Follower										7	262 270	-	8	272	265,000	4,5 or 9	250	0
X4	V4	5687	Amplifier	1 9	103 315	14,000 15,000							2 7	16 0	130,000 510,000	3,6	19	10,000	4,5 to 8	6.3ac	>0
X5	V5	6AU6	Amplifier	5	132	15,100	2	0	0	6	75	15,000	1	0	450	7	0	0	3 to 4	6.3ac	>0
X6	V6	6AH6	Discharge	5	262 270	-	2	0	0	6	154	33,700	1	0 1.4	270,000	7	4.8	1,300	3 to 4	6.3ac	>0

[a]From Army Technical Manual materials.

Figure 7

Chapter 3

THE FORECAST SYSTEMS ANALYSIS

A BASIS FOR TROUBLESHOOTING

Depending on the circuits involved, making deductions from symptom information about the condition of electronic parts can be easy or difficult. In some cases the process can be so complex that even the person who designed the circuit may not be able to deduce what parts are causing certain malfunctions. Although Army electronics schools today devote 30 or more weeks to radar repair training programs, even this is recognized as being too short a time for a repairman to acquire a fund of electronics knowledge that would enable him to make all the deductions necessary for locating all malfunctions of a radar system.

As a matter of fact, it is not possible to identify all malfunctions on the basis of theoretical knowledge alone. The more electronics a repairman knows, the more he can deduce about the specific location of a malfunction from signal-flow information. Even with perfect electronics knowledge, however, he will reach a point at which a signal reading will be ambiguous, because it is produced by the interaction of a number of parts or chains of parts, each of which contributes to the signal.

In design work, engineers recognize that theory alone is not sufficient—that "breadboarding" also is needed—because the components in real equipment do not correspond exactly to theory. For example, there is some capacitance in resistors and inductors, some inductance in resistors and wire, and some resistance in inductors. These practical facts differ from the theory used in design. Engineers know they must take the discrepancies into account while they are developing equipment designs, and they therefore use breadboarding to bridge the gap between theory and practice.

A similar bridge is needed in the field of electronic-equipment repair, but the need is not fully recognized. No systematic effort is being made to generate the type of practical information that clarifies repair problems as breadboarding information helps with design.

A guiding proposition of the FORECAST approach is that it is not reasonable to expect repairmen to solve, on a theoretical basis, the kinds of problems that design engineers must solve on a practical basis. It is true that the current method of training enables a repairman to locate some of the possible malfunctions in a system, but the percentage of success is debatable. The direction of FORECAST research is toward raising this percentage by establishing training procedures to help the repairman move from theory to practice.

AN ORGANIZATION OF SYSTEM INFORMATION

As in the present training philosophy, the FORECAST concept is concerned with the body of electronics knowledge from which troubleshooting deductions may be made. What distinguishes the FORECAST approach is the emphasis made upon organizing, and placing at the disposal of the repairman, the practical knowledge he needs in order to use his theoretical information.

Essentially, the FORECAST approach begins with the use of FORECAST-developed analysis procedures used by experienced and highly competent electronics technicians who serve as analysts. Their analysis consists of selecting and ordering the type of information that bridges theory and practice applied in troubleshooting. The information resulting from this system analysis can be packaged in a form easily passed on to the repairman and easily used by him.

Of the different kinds of electronics information, two are of major importance for maintenance: One is to know what the measured values at various points in the system should be, and the other, what portions of the system affect the values measured at those points. These kinds of information are essential for operating, adjusting, troubleshooting, repairing, checking, using Ord 6, or any other phase of maintenance, although the combinations and amounts of information needed differ for different phases. Operation of the system does not require the knowledge of as many measured values or parts affecting those values as does troubleshooting; similarly, adjustments do not require knowledge of the same set of values and parts as system operation, nor is the amount needed as great as that for troubleshooting. For the present, let us consider only the knowledge needed in troubleshooting.

Checkpoint Selection

Troubleshooting in the electronics field is possible because of certain characteristics of electronic equipment, one of which is that values measured at various places in the system are affected by portions of the system of widely varying size. For example, a measurement at one point may be affected by 5,000 individual parts while a measurement at another may be affected by only a hundred parts, or ten parts, or one. This fact makes it possible for a troubleshooter to narrow the malfunction to a single part by using a series of increasingly specific tests. This being the case, it is evident that a key question for the analyst is: What set of measurement points should the analyst select for the repairman to use in order to do his job effectively?

One answer might be that he should know, or be able to compute from theory, the correct value at every possible point in the system. Even if knowledge of such breadth were "ideal," something less than this might provide what the repairman needs to do his job, and furthermore is likely to be more efficient. The problem therefore becomes one of selecting a minimum but sufficient system of checkpoints. (While the FORECAST principles employed in checkpoint selection are the same for Ord 6 and for system troubleshooting, the analyses might yield different checkpoints by taking into account differences in test equipment sensitivity and differences in accessibility of checkpoints.) If

every part in the electronic system can be covered at one or another of the selected checkpoints, and if measurements taken at these selected points will yield information by which the repairman can isolate any part, then knowledge of correct values at the selected checkpoints can be considered sufficient.

There is a general troubleshooting logic for electronic equipment: When a stage has good signal inputs but one or more bad outputs, the trouble must lie somewhere within that stage. The practical value of this simple and useful piece of logic has been limited because the specific parts contained within the stage are not readily identifiable in practice. The FORECAST approach is to determine in advance of any malfunction and on a practical basis just what parts can affect a measurement made at the checkpoint that defines the stage output. It can be established that these parts and only these parts can affect the reading, and that none of them can affect a measurement made at a checkpoint earlier in the signal flow. The analysis selects a set of the appropriate checkpoints throughout the system and, where feasible, indicates the tolerances for the measurement to be taken at each point.

The process is systematic and organized, and its product constitutes the bridge between theory and practice. It is a way of applying the simple logic of the thought that "If it goes in good and comes out bad, the trouble is in that block."

Limits of the Troubleshooting Block

In current electronics training programs, block diagrams that summarize the various stages and channels of the electronic system in terms of their function are sometimes used to give the student a general understanding of how the system works. These functional diagrams are not intended to be practical troubleshooting guides because the simple logic of troubleshooting, a good signal in and a bad signal out meaning a malfunction in that block, does not necessarily hold for them.

The FORECAST type of analysis produces an organization of the electronic system into a series of troubleshooting blocks having the purpose of communicating to the repairman practical bridge information. Determination of the limits and components of these blocks is the main task performed by the technical experts in their analysis of the system. Detailed schematic diagrams provide the basic printed material upon which the troubleshooting blocks can be imposed (see Fig. 3, p. 12).

The arrangement of the system into a relatively large number of troubleshooting blocks provides a vehicle by which the student can learn the over-all functioning of the system in sufficient detail for troubleshooting, but without so much detail on circuitry that he loses sight of the over-all system. Organization of information so that the system relationships will be presented at this level of detail is one of the critical features of the FORECAST approach.

Troubleshooting logic is appropriately applied to linear chains in which the signal moves in one direction and can be traced along its path. However, the signal-flow information cannot be used to identify individual malfunctioning parts, because the path the signal follows is

not the only path in the system—there are also groups of parts, or small chains of parts, which converge to produce desired alterations in the signal. The signal-flow information may not always show which of a number of converging chains is causing the interruption, but it will show if there is a malfunction in one of them. In the FORECAST process, the analysis by system experts is used to determine on practical grounds the point at which signal-flow information becomes ambiguous. This point marks the limit of the troubleshooting block.

This block organization makes it possible to use troubleshooting logic to troubleshoot to a single block, which is made up of a comparatively small group of parts. Within this block, another type of measurement will be used to investigate each of the converging chains independently.

Within-Block Troubleshooting

Signal-flow analysis is abandoned at the point--always at the edge of a troubleshooting block—where a reading would be subject to more than one interpretation. The same logic that supports a signal-flow analysis is applied within the troubleshooting block, but the method of measuring is changed.

The more detailed system analysis is based on resistance measurements to be taken at the tube pins, the points at which the parts or chains of parts converge and are attached. Thus, a bad reading at a pin would indicate that the parts attached there should be checked individually. Good readings at all the points would indicate that the block should be checked for those hidden parts whose malfunction would not affect tube-pin readings but would nevertheless effect troubleshooting block output signals. The analysis produces the information that a repairman would need in order to identify and measure these hidden parts.

IMPLEMENTING THE FORECAST METHOD[1]

Systems experts first determine, on the basis of theory, what parts can affect measurements at the selected checkpoints. They verify their determinations on the equipment itself, a process that takes relatively little time because in the system analysis all the critical measurements to be made have already been identified. The experts then correct their initial errors, and recheck the results. The fact that these electronics experts, with ample time at their disposal, make many errors in their initial determinations on the basis of theory is a graphic indication of how difficult it is to make such practical determinations, and why it is valuable to have the experts' analysis prepared before the malfunction occurs. Their analysis, covering every part of the equipment, insures that correction of even infrequent malfunctions can become part of the repairman's troubleshooting repertoire.

[1]Edgar L. Shriver, C. Dennis Fink, and Robert C. Trexler, *A Procedural Guide for Technical Implementation of the FORECAST Methods of Task and Skill Analysis*, training manual, Training Methods Division, Human Resources Research Office, Alexandria, Va. (published in Washington, D.C.), July 1961.

The experts mark existing schematic diagrams to indicate the limits of each group of parts, or troubleshooting block, in the system. They also stipulate the appropriate checkpoints and the measurements to be made at each point, and record hidden-parts information. The sufficiency of the checkpoints which emerge from the organization of the system into troubleshooting blocks is tested and verified as a final step in the analysis of the system.

The supportive documents that can be prepared from this analysis may be used both for training and in the field. The troubleshooting block diagrams, in particular, not only provide practical information that cannot be deduced from theory but also reduce the amount of electronics data the repairman must remember, while actually increasing the amount of effective information available to him for use in troubleshooting.

The various documents, listed below, serve the following purposes:

Troubleshooting block diagrams support the process of—

(1) Interpreting symptoms in terms of areas of the equipment that might contain the malfunction producing the symptom.

(2) Selecting checkpoints to isolate trouble to a block.

Checkpoint sheets support the process of isolating the trouble to one block by—

(1) Giving checkpoint locations.

(2) Indicating the test equipment to use, settings of test equipment, operational mode of systems, and any special testing procedures or instructions required.

(3) Listing standard and normal readings with which to compare results obtained.

Schematics are blocked for piece-part troubleshooting by—

(1) Indicating which specific points may affect the checkpoint readings.

(2) Providing information for use in determining which parts, if bad, will not affect pin readings.

Resistance and voltage charts provide normal pin readings.

Once system design engineers or other highly competent experts have prepared this information according to the guidelines that insure its usefulness to the repairman, the information can be incorporated in the repairman's training program and should at the same time be incorporated in the schematic diagrams and text of pertinent Army technical manuals.

In a FORECAST type of training program, the block diagrams showing the troubleshooting blocks would be given to the students, who would be taught how to use them in conjunction with analysis of the signal flow. For identifying the malfunctioning part within the block, the training program would provide extensive practice in applying practical rules for making pin-resistance measurements and for determining and measuring parts that cannot be checked by resistance readings made at tube pins. Information regarding the use of test equipment, adjustment procedures, color codes, some electronics theory, and similar material would be included in the training course, in addition to the information based on the FORECAST analysis.

Army experience in implementing the FORECAST concept of electronic system repair is being obtained in the Improved Nike-Hercules HIPAR course being conducted at the U.S. Army Ordnance Guided Missile School, Redstone Arsenal, Alabama. The FORECAST type of training is being used in the portions of the course dealing with system troubleshooting, system functioning, and over-all understanding.[2]

[2]See Edgar L. Shriver, C. Dennis Fink, and Robert C. Trexler, *Implementation and Checkout of the FORECAST Concept of Electronic System Repair at the U.S. Army Ordnance Guided Missile School*, Consulting Report, Training Methods Division, Human Resources Research Office, Alexandria, Va., August 1963.

Chapter 4

CUE-RESPONSE TRAINING METHODS: MOCK-UP EQUIPMENT

UTILIZATION OF SURROGATE AND MOCK-UP EQUIPMENT

Observations by research personnel during the FORECAST I experimental M33 course suggested that much of the skill and knowledge an electronics troubleshooter must develop seems common to repairers of all electronic equipment. Skills that are common could be learned on any energized, fairly complex weapon system. It seemed likely, especially with FORECAST troubleshooting procedure, that a considerable portion of the training program for one system might be accomplished by using as a training device another system, readily available because of being older or even obsolete.

Furthermore, analysis of the training content in the experimental M33 course suggested that most of the training may be viewed as teaching the following:

- Operational skills
  - Procedures for energizing and de-energizing system
  - Procedures for checking equipment operation
  - Use of common test equipment
- Recognitive skills
  - Recognition of correct and incorrect appearance of external indicators
  - Recognition of correct and incorrect operation of external controls
  - Recognition of correct and incorrect troubleshooting block outputs
- Interpretative skills
  - Relation of external symptoms to system areas
  - Relation of block outputs to malfunction location
- Troubleshooting logic
  - Logic employed in FORECAST troubleshooting approach (system troubleshooting logic as applied to FORECAST material)
  - Functional understanding of system areas

Teaching much of the above material, it was believed, could be accomplished through the use of mock-ups rather than operational equipment. Such devices need not, in fact, duplicate either the appearance or circuitry of the real equipment, since the requirement for instruction is simply that the cues and responses be simulated in a fashion that allows learning of the relevant aspects of the task.

A mock-up that simulates to some extent the external features of a piece of equipment but does not duplicate its internal circuits, for

example, could be used to teach such elements of the cue-response training as operator skills, external indications of malfunctions, and various checks and procedures. A mock-up, simulating the relevant portions of the system's internal functioning, could be used for teaching such activities as isolating malfunctions, selecting checkpoints, and interpreting readings.

Essentially, operational performance may be said to consist of the interpretative and decisional skills listed above, as well as certain other skills and knowledges, primarily familiarizing and mechanical, that can only be learned by practice on energized equipment. These latter skills are in part teachable on obsolete equipment, in part only on the operational new equipment itself.

The prospects for use of surrogate and mock-up equipment in the FORECAST-type training have special interest in connection with training for new weapon systems. The training problem posed by a new system does not end with development of training program content but continues during the administration of training, because of the scarcity of equipment. Present courses for upcoming weapon systems attempt to overcome this training handicap by extensive use of diagrams, slides, and photographs of the new equipment and similar training-aid techniques. This does not, however, solve the problem of teaching skills that can only be learned on energized equipment.

Research was therefore undertaken to explore the feasibility of using available weapon systems as the major training equipment in a course of training for a new system. The course was to include paper-and-pencil and mock-up training aids for teaching knowledges and skills that are specific to the new equipment. The emphasis, however, was to be placed on an attempt to produce troubleshooters who have already developed the necessary troubleshooting skills and confidence on real equipment before they come into contact with the equipment of the new system.

This chapter contains reports of:

(1) A baseline experiment which provided (a) transition from FORECAST I research conditions and (b) a vehicle for exploratory work.

(2) A study in which mock-up devices were substituted for energized equipment in part of the training.

Experimentation along these lines was continued in another study, described in Chapter 5, in which surrogate equipment was utilized in experimental training for transition between systems.

BASELINE STUDY

As a preliminary step, a baseline study was conducted to obtain an estimate of the proficiency which could be expected from students training on only one subsystem (the tracking radar) of the M33. This information would be compared with results in the FORECAST I study, in which the students had been trained on all four M33 subsystems, and it would serve as a basis for evaluating student performance on one subsystem in the specific experiments that were planned.

In addition, this study was used to investigate a question basic to the later mock-up and transfer of training experimentation: How much

practice on real equipment does a student need to support the troubleshooting information he learns in class?

In their training on the four subsystems of the M33, the FORECAST I students had received many hours of practice on real equipment. A certain amount of such practice is needed not only to enable the student to learn the many skills essential to applying classroom-type knowledge rapidly and effectively to real systems, but for more basic reasons as well: He must have the opportunity to lose his initial awe of the system and his fear of high voltages, and to acquire confidence in his ability to troubleshoot.

On the basis of earlier studies, the research staff estimated that trainees would need at least a week of work on real equipment for acquisition of these general skills and attitudes. Students in the Baseline study were therefore given 39 hr. of real equipment time in their 145-hr. course. (For subsequent change in hours of training, see pp. 27 and 32.)

The initial step in organizing the training content into general and system-specific types was also taken in this preliminary study. One portion of the instruction dealt with general information needed for repairing any electronic system, and the other portion was specific to the track subsystem of the M33. The content of the training program is summarized in Table 1, together with the content used in the subsequent mock-up and transfer studies.

Table 1

Training Content for FORECAST Studies

Summary of Training Hours

Content	Baseline Study (Track)	Mock-up Study (Track)	Transfer Study (Acquisition)	Transfer Study (Common)	Transfer Study (Track)
	Hours	Hours	Hours	Hours	Hours
I Instruction					
Classroom conferences, reviews, and tests	46	46	30	–	42
Classroom practical exercises	5	11	–	19	–
Miscellaneous practical exercises on M33	2	2	–	2	–
Operator training M33	4	1	–	1	–
Mock-up	0	6	–	3	–
Soldering	6	6	–	6	–
Chassis navigation	7	6	–	6	–
M33 adjustments	15	8	8	–	5
Total	85	86	38	37	47
II Troubleshooting exercises					
M33 troubleshooting (system)	39	29	23	–	9
Mock-up troubleshooting (system)	0	24	13	–	28
Within-block troubleshooting	21	34	–	15	–
Total	60	87	36	15	37
Total training hours	145	173	74	52	84
				210	

The lesson plans for both the general and specific systems were essentially the same as those used in presenting these topics for the experimental group in the FORECAST I study, although some explanations were added. The similarity of the repair performance of the Baseline group and the experimental group was determined experimentally, with the fact in mind that the Baseline group learned only the track subsystem while the earlier group had learned this subsystem along with the other M33 subsystems.

The ability of the Baseline students to troubleshoot the track portion of the M33 was assessed on the track subsystem portion of the M33 Repairman Proficiency Test used in the FORECAST I research (see App. C). This represented a practical test of the repairman's ability to repair malfunctions that actually have occurred in the field.

The performance of the students is summarized in Table 2. Even though their training was on one subsystem, the Baseline group performed at the same level as the average of the two groups in the FORECAST I study. Total scores were 50.7% vs. 49.4% of total possible score. The evidence indicates that the 39 hr. of real-equipment practice given the Baseline group was sufficient for them to learn the supportive skills as well as both FORECAST I groups had learned them in the full M33 training program.

Table 2

Scores Obtained on Practical Test of System and Within-Block Troubleshooting Proficiency

Group	System Troubleshooting (to malfunctioning block) %	Within-Block Troubleshooting (to malfunctioning part) %	Total %
FORECAST I			
Standard	57.7	39.5	48.6
Experimental	60.8	44.8	52.8
Baseline	60.9	37.8	49.4
Mock-up	84.8	60.3	72.6
Transfer	70.0	55.6	67.3

SUBSTITUTION OF MOCK-UPS FOR REAL EQUIPMENT

The Mock-up study assessed the effectiveness of a low-cost mock-up as a teaching device which would be substituted for real equipment in certain parts of training based on FORECAST methods. Since the major problem considered in this study was that of minimizing use of real equipment in training, the primary objective was to combine mock-up and real-equipment practice during training with production of high proficiency as the goal, rather than to evaluate use of the mock-up alone.

Training Program

The lesson plans used for the Mock-up class were the same as for the Baseline group. The primary difference in the training procedures for the Mock-up class was the practice provided on mock-up equipment for the M33 track subsystem. Twenty-four hours were added to the training periods for practical exercises on the mock-up; the number of hours of practical exercises on the real M33 equipment was reduced by 10 hours. Practice on within-block troubleshooting was increased by 13 hours.

The net result of these changes was to increase the over-all track subsystem training time by 10%, as compared with the Baseline and the FORECAST I experimental groups. Since the training time for the FORECAST I experimental group represented a 60% reduction from standard training, the Mock-up study changes, if extended to the entire experimental M33 program as conducted in the FORECAST I study, would produce a 50% rather than a 60% reduction from the standard training time.

During mock-up training sessions the students learned the interpretative and decisional skills and knowledges necessary for troubleshooting the tracking portion of the M33. The mock-up equipment dealing with maintenance was constructed to fit the FORECAST type of training content. It was used to familiarize the student with the relationship of the troubleshooting blocks to one another, and with the symptoms their malfunctions produce. The student obtained practice in deducing which block was malfunctioning when he pieced together the pattern of symptoms and indications that the mock-up presented.

Description of Mock-Ups[1]

Several pieces of mock-up equipment were developed. The operating and energizing mock-ups (Figs. 8 and 9) simulated the external features of the M33 track subsystem but not its internal functioning. These mock-ups could be used to teach operator skills, and recognition and interpretation of external indications . malfunctions. The student could learn the procedures for energizing and operating the equipment, and the operational checks to make when checking out the performance of the equipment (operational skills). He could also learn what portions of the system must be malfunctioning in order to produce certain external symptoms (recognitive skills) and, once the symptoms were interpreted, he could isolate the malfunction to a system area (interpretative skill).

The maintenance mock-up (Figs. 9 and 10) simulated the internal functioning of the system, but not its appearance or its circuitry. It consisted of a series of boxes, each representing one of the

[1]For a detailed description of the FORECAST mock-ups, see Shriver, *et al., op. cit.*, July 1961. A revised version of the FORECAST maintenance mock-up is currently in use at the U.S. Army Ordnance Guided Missile School. Description and use of this mock-up are discussed in: C. Dennis Fink, Robert C. Trexler, James E. Birdsall, and Edgar L. Shriver, *FORECAST Mock-Up System: Technical Description*, Training Methods Division, Human Resources Research Office, Alexandria, Va. (published in Washington, D.C.), September 1961.

troubleshooting blocks depicted on a FORECAST troubleshooting diagram of the equipment. By means of a switchboard the instructor could bring about either good or bad output of a box. This structure was based on the fact that troubleshooting blocks are conceptual areas in the equipment, each representing a portion, generally functional, of the system. The portion usually consisted of a small number of tubes and their associated parts, "assigned" to this block by practical analysis of the circuitry.

In the mock-up, the boxes are usually connected by simple electrical circuits to a pair of plastic squares upon which either a good or a bad wave form is drawn. These wave forms are the outputs of certain defined system areas. Other boxes representing system areas which are more appropriately tested by voltage measurements are constructed so that a good or bad voltage reading can be obtained from them.

The mock-up was used to teach the procedures for isolating a malfunction to a small area of the equipment. Among other things, it can be used to teach the proper selection of checkpoints and how to interpret wave forms and voltage readings (recognitive skills). The box outputs are used by the student to determine which troubleshooting block contains the malfunction (troubleshooting logic). If the student wants to check a block whose output is a voltage, he plugs a multimeter into the box representing that block; if the output is a wave form he inserts a probe which causes the output drawn on a plastic square to be displayed. The instructor decides, on the basis of the training program, the type of wave form or voltage (good or bad reading) which each box will produce when measured.

Performance

On the Track Subsystem Proficiency Test, the Mock-up group obtained an average score of 72.6%—20% or more above the scores of the FORECAST I groups and the Baseline group.

The difference between the Mock-up group and the FORECAST I experimental group is significant beyond the .01 probability level (t=3.2, 23 df). The difference between the Mock-up and Baseline groups is significant at the .06 probability level (t=2.2, 8 df). Thus the Mock-up group's performance was reliably superior to both the FORECAST I experimental and the Baseline groups.

On the to-the-block, or system, troubleshooting items, the Mock-up group's average score (84.8%) was 24% more than that obtained by the FORECAST I experimental group and the Baseline group, and 27% more than the FORECAST I standard group. On the within-block, or piece-part troubleshooting items, the Mock-up group's score (60.3%) was 15.5% more than the FORECAST I experimentals, 22% more than the Baseline group, and 21% more than the FORECAST I standard group.

It might be noted that 95% of the Mock-up students had identified the chassis containing the malfunction within five minutes (average) and were working within the chassis to find the bad block and part for the remainder of their limited test time (20 min. on the average for each item).

Discussion

Use of Mock-Ups in Training

Since a total of 39 hours on the real equipment had been devoted to system troubleshooting in the Baseline Study, the Mock-up Study was planned for the same amount of practice, divided between the mock-up (24 hr.) and the real equipment (15 hr.). At the end of 15 hr. on the real equipment, however, the research staff concluded that the students had not yet mastered many of the general skills required for working on real equipment. They were therefore given an additional 14 hr. of practice on the real equipment, making a total of 53 hr. instead of 39.

This modification makes it impossible to determine the exact contribution of the maintenance mock-up to troubleshooting proficiency. Instead, there is an empiric determination of the total effect of the combination of mock-up and real equipment practice. This effect may be interpreted as the sum of the isolated individual effects of real equipment and mock-up as well as whatever improvements in training efficacy may result from one to the other.

In to-the-block troubleshooting, a proficiency increase of 24% was attained by the Mock-up group by means of training procedures which reduced the amount of practice on real equipment by 25%. In within-block troubleshooting, the increase of from 15.5% to 22% over the previous groups' performance would seem to have resulted from the increased practice (13 additional hr.) given the Mock-up group.

It would appear that the higher proficiency of the Mock-up group is largely attributable to the use of a mock-up as a training device for to-the-block troubleshooting. At present, the reasons why the mock-up - real-equipment training sequence was more effective than equipment training alone are not definitely known. However, observations made during the studies suggest possible answers.

During the mock-up sessions, students acquired operational and interpretative skills, and practiced applying troubleshooting logic to a particular system. During the real-equipment sessions, the students learned the location of parts and practiced the mechanical skills necessary for rapid troubleshooting. Apparently different things are learned in each type of training. Possibly it is easier to learn these sets of skills separately than to try to learn them all at once on the equipment. Or it may be that the practice provided by the mock-up equipment allowed the system logic to be learned more effectively.

In any event, whatever the specific reasons for increased proficiency, the fact remains that <u>all</u> the above skills are necessary for troubleshooting. By use of the mock-up equipment these skills were acquired in training that reduced the amount of practice on real equipment by 25%.

To utilize the mock-ups in the traditional course, some of the main points of the FORECAST approach would have to be adopted in preparing material for instruction using the mock-up equipment. The system would have to be analyzed into blocks to fit the mock-up equipment, and the outputs of the blocks would have to be identified and

listed in order to provide mock-up block output. To describe the outputs of the various data channels of which the blocks consist, cues and symptoms of the system would have to be organized according to FORECAST methods. In effect, the traditional course would be largely transformed into a FORECAST course.

Characteristics of Training Devices

Military training programs have, for some time, used various types of training devices in attempting to handle the problem of unavailable equipment. Most of these training devices have been either inexpensive, locally constructed items or high-fidelity simulators of costly contract manufacture. The type of mock-up used in the present study fits between these two extremes. It is a medium-fidelity system of low enough cost that small groups of students may each have a practice set.

Because of the expected shortage of real systems, the extent to which medium-fidelity mock-ups, based on the same equipment analysis as the training content, can be substituted for the real equipment is an important question.

It is obvious that training devices are applicable for teaching only certain portions of the total maintenance task. How much can be taught in this way depends, in many instances, upon the manner in which the training device is constructed. A common assumption is that the usefulness of a training device is in proportion to the extent that it duplicates the equipment it is simulating. This viewpoint leads to a requirement for a high-fidelity simulator, which is usually expensive. A less costly and perhaps better approach is to design training devices to handle particular portions of the training program. Then, any feature included in the device not specifically needed for this portion of the training program becomes irrelevant, adding to cost and possibly detracting from the teaching objective.

The FORECAST staff constructed inexpensive training apparatus which, though unlike the operational equipment in appearance, proved effective for training by simulating the psychological environment in which the behaviors were to occur.

Thus, if one portion of the troubleshooting task is to isolate the malfunction to an area of the equipment called a troubleshooting block, then the training device must simulate these troubleshooting blocks, but need not look like the equipment represented.

Chapter 5

CUE-RESPONSE TRAINING METHODS: TRANSFER OF TRAINING

The general objective of the Transfer study was to investigate the degree to which skills and knowledges learned by a trainee on one radar subsystem will be usable by him on a second such subsystem when both have been analyzed by FORECAST methods. Experimental maintenance training, using FORECAST-type material and procedures, was devised to explore (1) transition training from one electronic system to another, and (2) use of one readily available system as a device in training for work on another system.

TRANSITION TRAINING PARADIGM

The idea that much experimental M33 course material deals with general skills that might be learned on any energized, fairly complex weapon system carries implications for potential transition training to a new-generation system. Similarly, it has implications as to the extent to which maintenance personnel might feasibly be trained to perform maintenance for more than one system, assuming the systems had undergone FORECAST analysis.

If an appreciable portion of a training program were of general applicability, transition training would consist simply of teaching the system-specific materials. Thus, multi-system capacity could be accomplished through general training conjoined with a series of system-specific portions.

To explore this problem, the transition paradigm was simulated by using the two obsolete M33 subsystems as training vehicles. The skills and knowledges viewed as being common to the repair of all electronic systems were taught on the M33 acquisition radar subsystem, representing the obsolete equipment. The M33 tracking radar subsystem served as simulated new-generation equipment.

Thus, the experiment consisted of giving general instruction on the "obsolete" system, adding some system-specific material that had a counterpart in the new system, and determining the degree to which savings could be made in training for the new-generation system. Consequently, in the new-system portion of the training, time did not have to be spent to teach the more general materials already learned; the additional training time could be interpreted as an estimate of how much system-specific training time would be required.

New systems are not radically different from the systems that preceded them, and changes are mainly state-of-the-art improvements. The differences between the M33 acquisition and tracking subsystems

are probably greater than between corresponding subsystems on any two Nike systems. The subsystems used in the experimental paradigm are, however, similar in the circuitry employed and, more importantly, the same troubleshooting procedures are readily applicable to both systems. This approach assumes that many skills and knowledges acquired on mock-ups and surrogate equipment can be readily applied by trainees to other similar equipment. Since such similarities are common to most electronic systems, training repairmen across systems is likely to be practical when each system is analyzed by FORECAST methods.

TRAINING PROGRAM DESIGN

The Transfer study is designed to simulate development of a program to train for the maintenance of a new weapon system or to train one man to repair several systems. In either situation, to be timely most of the training programs would have to be conducted on mock-ups or surrogate equipment because of the scarcity of the new equipment.

The similarity in electronics principles between systems suggests that an economical training program for maintaining a new system is one that (1) teaches skills and knowledges common to both the existing and the new systems, using the readily available obsolete equipment, and then (2) teaches the special characteristics of the new system, including the minimal necessary instruction on the new equipment itself.

On the basis of their experience with maintenance training, the experimenters estimated that for the M33 subsystem, practice time on the real equipment could be reduced to as little as nine hours (about the time required to learn the location of chassis and checkpoints), with reasonably high proficiency still expected. The amount represents only about 25% of the real-equipment practice time given in the Baseline and FORECAST I studies. To compensate for the lack of practice time on the real system, additional training time would need to be provided on mock-up equipment and obsolete equipment.

TRAINING CONTENT

The 210-hr. training program consisted of the following:

(1) 111 hr. of system (to-a-block) troubleshooting training on the M33 acquisition radar subsystem (including 37 hr. of common topics such as soldering and operator training) followed immediately by

(2) 84 hr. of system troubleshooting training on the M33 tracking radar subsystem;

(3) 15 hr. of within-block troubleshooting training which emphasized the troubleshooting of tracking radar chassis, distributed throughout the training program.

The hours of training time devoted to each major training topic during this study are summarized in Table 1 (p. 25).

The content for the acquisition radar instruction was essentially the same as that used during the FORECAST I study; much of the lesson material was refined and adapted to use with mock-up equipment but few content changes were made. The content for the tracking radar

instruction was identical with that used in the Mock-up study. Within-block troubleshooting material was essentially the same as that used during the FORECAST I and Baseline studies, though amount of time devoted to practical exercises was somewhat reduced. Since the Transfer study was specifically concerned with the transfer of system trouble-shooting skills and knowledges, and since few chassis troubleshooting skills and knowledges are specific to the chassis of one system, this type of troubleshooting was not especially emphasized.

During the acquisition radar (obsolete system) instruction, system troubleshooting was taught on a mock-up and on energized acquisition subsystem equipment (see Table 1). Live-equipment troubleshooting was emphasized in order to teach the students the general skills and knowledges necessary for working around energized equipment.

During the tracking radar instruction, considerable time was spent in system troubleshooting on the FORECAST maintenance mock-up. Only nine hours of real-equipment troubleshooting on a tracking radar were given during this period. In other words, as a substitute for real (track) equipment time in the Transfer study, a total of 64 hr. of practice was provided, 28 hr. of mock-up time on the track subsystem and 36 hr. of obsolete-equipment time on the acquisition subsystem.

The Baseline group had received 39 hr. of practice on the real equipment—30 hr. more than the Transfer (Track) group received. The question to be answered in the Transfer study is: Can the things learned in 64 hr. of practice on equipment (mock-ups and obsolete) other than the real system apply well enough to new-system duties to enable this practice to be substituted for 30 hr. of practice on the real system? If the measured proficiency of the students is as high in the Transfer group as in the Baseline group, or higher, this combination of substitute training will be considered to have sufficient transfer value.

Of course, many questions about transfer cannot be answered by this study. Other studies would have to be conducted to determine, for example, the precise transfer value and the parameters of each type of substitute training (mock-up and obsolete equipment). The purpose of this study is to answer the general question of transfer already posed and, by doing so, to establish an estimate of the proficiency to be obtained if the experimental combination of substitute training is followed in practice.

PERFORMANCE

The ability of the Transfer students to energize, adjust, and troubleshoot the M33 tracking radar subsystem was assessed on the same end-of-course proficiency test used in the earlier studies. The test scores are listed in Table 2 (p. 26). A t comparison between the Baseline and Transfer groups (mean scores of 49.4% vs. 67.3%) was significant beyond the .05 level of confidence ($t = 2.94$). A t comparison between the Mock-up and Transfer groups was not significant.[1]

[1]Raw scores were used in the t-tests. Percentages are used in the text for ease of comparing scores across the several conditions.

Thus, when the mock-up equipment and obsolete equipment are used in conjunction, the results are almost as good as when the mock-up equipment is used in place of the real equipment. This represents a high degree of transfer from old equipment to new when the mock-up equipment is used for appropriate parts of the training.

The Transfer group scores on the system troubleshooting items of the Tracking Subsystem Proficiency Test were 18% to 21% higher than the scores of the Baseline and FORECAST I groups. This greater proficiency in to-the-block troubleshooting was attained by training procedures that reduced the practice on the live tracking radar subsystem to nine hours.

The Transfer group also achieved a marked increase in proficiency for within-block troubleshooting over the Baseline students. This improvement is not readily explained because the Transfer students received less chassis troubleshooting training than the Baseline students. Better presentation of the material may account for the increased proficiency.

The transfer scores were within 5% of the mock-up scores on both to-the-block and within-block items, although the Mock-up students received 56% more practice on within-block troubleshooting (34 hr. vs. 15 hr.), and their to-the-block time (real-equipment plus mock-up practice on the tracking radar subsystem) totaled 53 hours compared with 37 hr. for the Transfer students.

This study has important implications for training when equipment has been subjected to FORECAST systems analysis and when FORECAST methods have been used in training. To a substantial extent, knowledges and skills learned in order to maintain one set of equipment can be used in another set of equipment. Therefore, obsolete equipment can be used for part of new equipment training and transition training for repairmen can be accomplished more easily and economically.

Chapter 6

CONCLUSIONS AND IMPLICATIONS

In the maintenance of electronic systems, troubleshooting is the most difficult problem to define and the most difficult skill to acquire. In large measure, Task FORECAST research has been directed toward defining and codifying troubleshooting performance, with emphasis upon indications of malfunctions (cue) and the repairman's reaction to an indication (response) rather than upon electronics theory.

Here are some of the conclusions and implications for operational use, arising from the FORECAST research and from initial work on implementation of the approach in military settings.

1. Training based on the FORECAST type of equipment analysis, using the cue-response paradigm, results in effective job performance, with a decrease in training time, on the operational and maintenance tasks in an electronic weapon system. This has been demonstrated in three studies, ranging from one in which graduates of a 12-week FORECAST course performed as well as those of the 30-week traditional course,[1] to one in which graduates of another FORECAST course performed 40% better than those of the traditional course.

2. FORECAST techniques can be used successfully to develop most training content from the kinds of information available about new weapon systems before they are in production. For the three studies mentioned above, the experimental courses were developed from schematics and other pre-production materials and then tested on the operational equipment. In a recent application of the FORECAST methods to an Army weapon system, the Improved Nike-Hercules HIPAR was analyzed by the FORECAST method one year before it reached the field for development of portions of the course of instruction.[2] As a result, for final training content analysts required only two weeks' work with operational equipment; thus graduates of this course could be trained and ready to maintain the equipment when it became operational.

3. Analysis of electronic equipment by FORECAST methods provides the basis for an effective troubleshooting process. A system of efficient cues and responses is selected and defined from the large number available, to provide the troubleshooter with the information that enables him, step by step, to narrow the source of a malfunction to the out-of-tolerance part or parts.

In essence, the FORECAST approach determines the smallest area to which dynamic signal-flow information can be applied

[1]Shriver, *op. cit.*, June 1960.
[2]Shriver, *et al.*, *op. cit.*, August 1963.

accurately in troubleshooting—the outline of the troubleshooting block on a schematic diagram. All parts are assigned to a block whose dynamic output they will affect. After the repairman traces a signal to the block in which the input is within tolerance and the output is out of tolerance, he uses static tests in order to identify the one malfunctioning part.

The key element in the FORECAST approach is the emphasis on organizing the practical knowledge needed as a bridge from theory, and placing it at the disposal of the repairman. The effects of malfunctions are correctly determined once, by experts. This information is then made available to the repairman in a form that provides the basis for rapid, accurate troubleshooting.

4. The FORECAST supporting products fulfill the function of providing rapid access to relevant information only, for each troubleshooting situation. They represent a way of packaging the results of the analysis in a simple usable form that strikes an effective balance between what the troubleshooter keeps in his head and what he has in his hand for reference. Among these products, applicable both for training and as job aids, are (a) a block diagram of the system; (b) a narrative description of the system signals which provides the basis for integrating and understanding symptoms and symptom patterns; (c) identification of dynamic signals at selected checkpoints, defined as block outputs, and indication of location, test equipment, and standard readings; (d) schematic diagrams blocked for troubleshooting, to show the boundaries of the system circuits where it is efficient to change from dynamic to static checks; and (e) a set of static tests for within-block checks on parts.

5. The use of the FORECAST methods of system analysis can be taught to experienced, competent electronics technicians and applied by them to develop training content. In the recent Army application of FORECAST methods on the HIPAR system, HumRRO representatives taught the equipment analysis concept and procedures to Army technician analysts, who then performed the HIPAR analysis on preproduction materials.[3]

6. The results of the mock-up study suggest that maintenance proficiency can be increased by the use of troubleshooting training devices. Such devices, if based on task analysis and properly designed, can be used to teach certain of the skills and knowledges required of the repairmen, particularly those needed to carry out the cognitive activities of troubleshooting. Students appear to learn some types of content more readily on mock-ups than on real equipment.

7. If devices such as the FORECAST mock-ups are incorporated into the type of training employed in the Mock-up and Transfer studies, it appears that training requirements for costly electronic equipment could be reduced. The repairman needs only a limited amount of equipment training time to acquire the skills necessary to work around live equipment. Even when equipment is in ready supply, there are definite advantages to using mock-ups in teaching certain aspects of the troubleshooting process. Among other things, mock-up practice makes it possible to eliminate the time-consuming procedures normally required

[3] *Ibid.*

to test real equipment; the student can use the time saved to practice the more difficult aspects of the troubleshooting process.

8. In designing a training device, the developer needs to determine not only what skills and knowledges must be imparted by training, but also how the device must be constructed for effective training. FORECAST studies suggest that an inexpensive medium-fidelity mock-up can be constructed which can be successfully used to teach conceptual activities such as troubleshooting.

9. The FORECAST approach can be applied to the problem of repairmen trained on one system being utilized on a newer system that has replaced it or after field changes have modified it. Experience in these studies indicates that suitable proficiency can be obtained with a transition training program even though training time on the new equipment has been reduced by as much as 75% from that currently used to achieve present proficiency levels.

The amount of transfer of training to be expected from the surrogate and mock-up equipment cannot be precisely stated. However, results suggest that this rate of transfer should be fairly high, particularly in those cases where the new weapon system is a second or third generation of that version used during the general initial training.

10. The results from the transfer study suggest that the methods explored in FORECAST would also be applicable in training repairmen to repair a number of different systems. Since skills developed in one complete training program include much that is needed for other programs, a course employing FORECAST electronics maintenance training allied with a series of system-specific programs could be used in producing multi-system competence within the time currently allotted for single-system training.

Since the FORECAST approach to troubleshooting involves changes in training methods used for more than 20 years, its implementation must be shown to hold good promise of substantially reducing or eliminating problems associated with the traditional approach.

The research that has so far been conducted has been designed to obtain indications of what training problems will be solved, and to what extent, by using FORECAST methods. Research has gone about as far as is useful in providing data; further indications must come from studying the results of preliminary implementation. Results of several steps already taken have been promising. The present report provides information with implications bearing on a number of the problem areas in which further implementation might take place.

Appendix A

SUMMARY OF FORECAST I RESEARCH[1]

Problem

Task FORECAST is concerned primarily with the training demands imposed by new weapon systems. The objective of the first phase of the research was to develop and test methods for analyzing an electronic weapon system to define a set of skills and knowledges for operating and maintaining the system.

Preliminary work indicated that the methods being developed would result in electronics maintenance training courses of much shorter duration than the standard course. Therefore, a joint Army/HumRRO decision was made in February 1958 to test the new methods immediately on an existing electronic weapon system, the M33 Antiaircraft Fire Control System. The purpose was to determine what effectiveness (increased job proficiency) and economy (decreased training time) could be obtained through the increased accuracy of the new methods in specifying job demands. The FORECAST I report describes the methods of analysis and the results of testing the effectiveness and economy of an electronics maintenance course derived from these methods.

Method

Two methods for analyzing electronic weapon systems were developed, one for the operator task and one for the maintenance task. Both methods identified a set of cues and responses which, when properly learned, should lead to effective operation and maintenance of the weapon system.

The operator analysis method identified and defined all cues and responses incorporated in the system by its designers. The method for analyzing the maintenance task involved rules for selecting and defining certain cues and responses rather than others. The methods differed because system developers built operators' cues and required responses into the machine in the form of displays and controls, whereas, for the maintenance task, the cue-response structure had to be imposed as a part of the analysis.

The methods of system analysis were used to derive sets of cues and responses sufficient for operating the M33 Antiaircraft Fire Control System, and for performing first and second echelon maintenance and third and fourth echelon repair. Also developed was a "story" which told how cues were related to each other, but specifically avoided telling how they were electronically produced.

[1]See Shriver, *op. cit.*, June 1960.

To insure that the analysis methods would be applicable for use on future electronic systems, the training program was based on the type of information (such as schematic diagrams) available before production of the M33 system. The rules developed for identifying the sets of cues and responses were stated in general terms, so that they could be used for identifying the cues and responses for other systems.[2]

The sets of M33 cues and responses derived from these analyses were given to students in a 12-week experimental electronic repair course. These students had been matched in background (years of education, and electronics and general training aptitude scores) with a group of students receiving the standard 30-week training for third and fourth echelon repair of the M33 system (Heavy Fire Control Equipment Repairman, MOS 232.1). This course sequence consisted of basic electronics training at the U.S. Army Signal School, Fort Monmouth, New Jersey, and advanced training at the U.S. Army Ordnance School, Aberdeen Proving Ground, Maryland.

Instructors of both groups used the same techniques of instruction, described in FM 21-6, Techniques of Military Instruction. The student-to-instructor and student-to-equipment ratios favored the 30-week standard group. Instructors of the standard group had much more teaching and electronics experience than instructors of the experimental group.

After graduation 17 students from the standard group and 20 students from the experimental group were tested on an objective nine-day performance test, the M33 Repairman Proficiency Test. The test required the subjects to troubleshoot for malfunctioning parts as many different chassis as the average repairman would work on during his first 8 to 12 months in the field; the test measured the subjects' ability to energize, adjust, and identify the malfunctioning parts (resistors, capacitors, etc.) in the electronic portions of the M33 system with common and special test equipment. A large number of work samples from the actual field job were included to improve estimates of true student ability.

Finding and Conclusions

Despite the fact that the experimental training time was less than half the standard training time, there were no practical differences in proficiency between the experimental and the conventionally trained groups.

The implications of this finding become more striking when it is noted that, by the design of the study, all factors affecting group performance were either equivalent or favored the standard students. The critical non-equivalent factor was the experimental variable, namely, the content of the training programs.

Since the experimental groups performed as well as the standard group, it is reasonable to conclude that the specific set of cues and responses used in training the experimental groups was as effective as the material used with the standard group.

Since the rules developed for identifying the set of cues and responses were general, similar sets of cues and responses can be identified for other electronic systems.

[2]See Shriver, *et al.*, *op. cit.*, July 1961.

Appendix B

STUDENT SAMPLES USED IN THE FORECAST II STUDIES

Baseline Study

The five students for the Baseline study were sent directly from Army basic combat training (BCT) to the U.S. Army Ordnance School, Aberdeen Proving Ground, Maryland. They had no previous experience with electronics. Their general technical aptitude area (GT) and electronics aptitude area (EL) scores from the Army Classification Battery and their years of civilian education are presented in Table B-1, which summarizes the measured background factors of the men in the five groups tested on the FORECAST proficiency test.

For the Baseline group the average GT scores and the average number of years of education were higher than the same averages both for the previous FORECAST classes and for the subsequent FORECAST II students. A difference in this direction should favor the Baseline group. However, the EL scores for this group were lower than in other groups due to a sampling error. While this error was not believed by the experimenters to be of sufficient consequence to rerun the study, it is a factor that the reader may wish to consider, together with the mitigating circumstance that the EL test is designed to select students for the conventional course. The selective factor for conventional course content does not seem to be of critical importance for the type of training discussed in this report.

Table B-1

Background Factors for Groups Tested on FORECAST Proficiency Test

Group	N	Average GT Score	Average EL Score	Average Years of Civilian Education
FORECAST I				
Standard	17	116	115	12.3
Experimental	20	115	108	11.6
Baseline	5	131	92	15.4
Mock-up	5	104	106	11.5
Transfer	6[a]	113	115	12.8

[a]The scores of one student, who failed, were not included in the results.

Mock-Up Study

Six students for the Mock-up study were sent directly from BCT to the Ordnance School. (One student did not take the test, for

nonacademic reasons.) This group had no previous experience with electronics. They had somewhat lower GT scores than students in the Baseline or FORECAST I study, and lower EL scores than the FORECAST group; they had higher EL scores than the Baseline group but less education. Thus, any higher proficiency of the Baseline group on the end-of-course test could not be attributed to any clear superiority over the other groups in aptitude or civilian education.

Transfer Study

The six students who participated in the Transfer study were sent directly from BCT to the Ordnance School. They had no previous Army experience with electronics. Their aptitude and education scores were similar to those of students previously trained by the FORECAST methods.

One student, whose low grades would have required repeating a section of the training if that had been possible in this study, was considered a failure. In this report, therefore, test scores for only the five passing students were used. If, however, the other student's scores had been included in the results listed in Table 2, the figures in the "Transfer" column would be changed to 52% and 75% respectively—a minor alteration which would not affect the over-all results.

Appendix C

THE TRACK SUBSYSTEM PROFICIENCY TEST

Items from the FORECAST I end-of-course test, the M33 Repairman Proficiency Test,[1] were used as the proficiency measure in the FORECAST II studies. Since assessment of performance was limited to the tracking portion of the M33, only the 36 items involving the track subsystem were used. This included 18 items from the van test, 12 items from the shop test, and 6 items from the warm-up test. The time allowed for completion of each item ranged from 5 min. to 1 hr. and averaged about 20 min. for each item.

The scores from these items were combined into two test scores, representing ability to troubleshoot to a block and within a block. The 18 van and the 6 warm-up test items comprised the "to-a-block" test. In the 12 shop items the student was expected to identify the malfunctioning part within a block (Within Block TS).

The Track Subsystem Proficiency Test included about one-third of the items in the FORECAST I test of the entire M33 System. The test included as many different track chassis as a repairman would troubleshoot, on the average, during his first 8 to 12 months in the field. The items were real troubles that had occurred in the field and were not keyed to the training in any way. The various types of test troubles were inserted in the system in approximately the same proportion as they occurred in the field, except that the proportion of field tube-malfunctions was slightly reduced to allow more piece-part malfunctions to be included.

The track test required about 2 1/2 days to administer to each student individually. Instructors served as test administrators and followed strict rules prohibiting conversing with students or giving them aid during the testing period.

[1]See Shriver, *op. cit.*, June 1960.