System Testing of the No. 1 Electronic Switching System

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Plans for testing the hardware and software and for evaluating overall system operation of the No. 1 electronic switching system are described. Program and hardware test facilities and the early results achieved using these facilities on the first two No. 1 ESS installations are presented.

I. INTRODUCTION

Planning for system testing started at the beginning of the No. 1 electronic switching system (ESS) development.[1] Test facilities were designed concurrently with the design of the system. This paper describes the test plan being followed, the test facilities that are being used and the results that were obtained on the first two No. 1 ESS installations.

The first No. 1 ESS, located at the Holmdel Laboratories, is being used for checking system design. The second No. 1 ESS at Succasunna, N. J., is the first of a large number of systems scheduled for commercial service.

Fig. 1 broadly illustrates three sequential periods of testing. Factory tests are followed by system tests and, after cutover of an office to service, by maintenance tests.[2] Fig. 1 also depicts system evaluation, an activity which has its beginnings in the planning and design stages and carries through many issues of a new system.

Factory testing is a subject on which there are many views. Most views include some degree of device and package testing, and inspection for workmanship — such as the quality of the wired connections. Beyond that they range from continuity checks of mounting plate assemblies and major units to functional tests of groups of major units or subsystems, and on out to rather complete system testing. The major units of the Holmdel system, after very little factory testing, were shipped directly to Bell Laboratories for extensive design testing prior to use in the

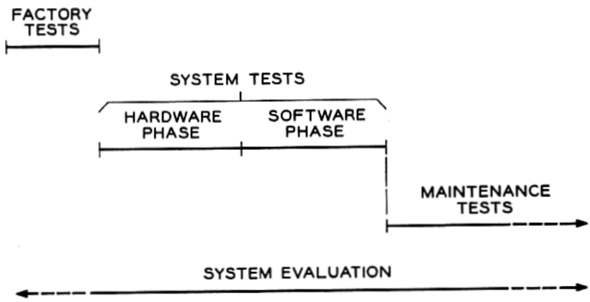

Fig. 1 — Test diagram.

system. With the availability of test specifications, the major units for the Succasunna system underwent considerable factory testing prior to shipment.

The system test interval (see Fig. 1) consists of two sequential phases, hardware and software (program). At installations beyond the early No. 1 installations the software phase will largely disappear. The debugging of programs which provide new features will be accomplished on the Holmdel system. When this point is reached, testing at the field site becomes what is known as "installation testing." This paper deals with system testing. However, much of the test planning and many of the facilities and techniques for system testing can be and are being applied to installation testing by the Western Electric Company.

II. HARDWARE TESTING

System hardware testing checks the proper functioning of all units as a system. The major units of the No. 1 ESS are the central control, program store, call store, central pulse distributor, and peripheral units. The peripheral units include the signal distributor, scanner, network, and master control center. The teletypewriter, automatic message accounting unit, memory card (program store memory) writer, and control display and test panel are all parts of the master control center.

For the first No. 1 ESS system at Holmdel, the hardware testing was intended to prove the system design both from the hardware and logic standpoints. Although most units had been individually tested, they had never worked together as a system. Many maintenance features,[2] such as those in the central control, could be tested only during system testing.

The hardware testing is done in two stages, manual and program. Manual testing comprises only a very small part of the total effort. The hardware testing is essentially accomplished by program means. Special programs, called "X-ray programs," were designed for this purpose. The term "X-ray" is used to convey the idea of examining the internal and basic functions of the system. Two aspects of hardware testing are the detection and location of troubles. The latter is by far the more difficult. One objective in the design of the X-ray programs was to simplify the method used in hardware testing. The programs developed not only detect troubles at system speed but also help in locating them easily and quickly.

2.1 *Manual Hardware Testing*

Manual hardware testing includes all tests not performed by use of X-ray programs. Many of these tests, such as power testing and continuity checking of interunit wiring, are rudimentary in nature and perhaps not properly classified under system testing. On the other hand, some manual testing, particularly that carried out on the Holmdel system, can be considered system testing — for example, the pulsing and monitoring of the systems communication buses[3] using pulse generators and oscilloscopes to ferret out system noise problems.

In the No. 1 ESS the central control is the basic control unit and the most complex unit in the system. It governs the flow of information and coordinates the action of all other units. The program store is used to store the program of the system and data such as the translation information associated with each customer.[4]

In the plan that is being followed for No. 1 ESS testing, the goal is to bring the central control and the program store to a state where they can be operated together on X-ray programs as soon as possible in order to fully test themselves and other units of the system. With a proper installation sequence, manual testing and in fact X-ray testing, can progress while many major system units are being installed. The total hardware test period, therefore, can be shortened.

Manual testing of the central control and program store primarily consists of testing the central control's ability to send addresses to and receive instructions from the program store. In addition, central control's ability to execute a few simple instructions is checked before X-ray programs are used. At the conclusion of these manual tests only a very small fraction of the vast amount of circuitry in the central control[5] has been tested. The manual testing of the central control and program store is carried out with the aid of a central control manual tester (see Fig. 2). This test set is mobile and plugs into a central control. Using

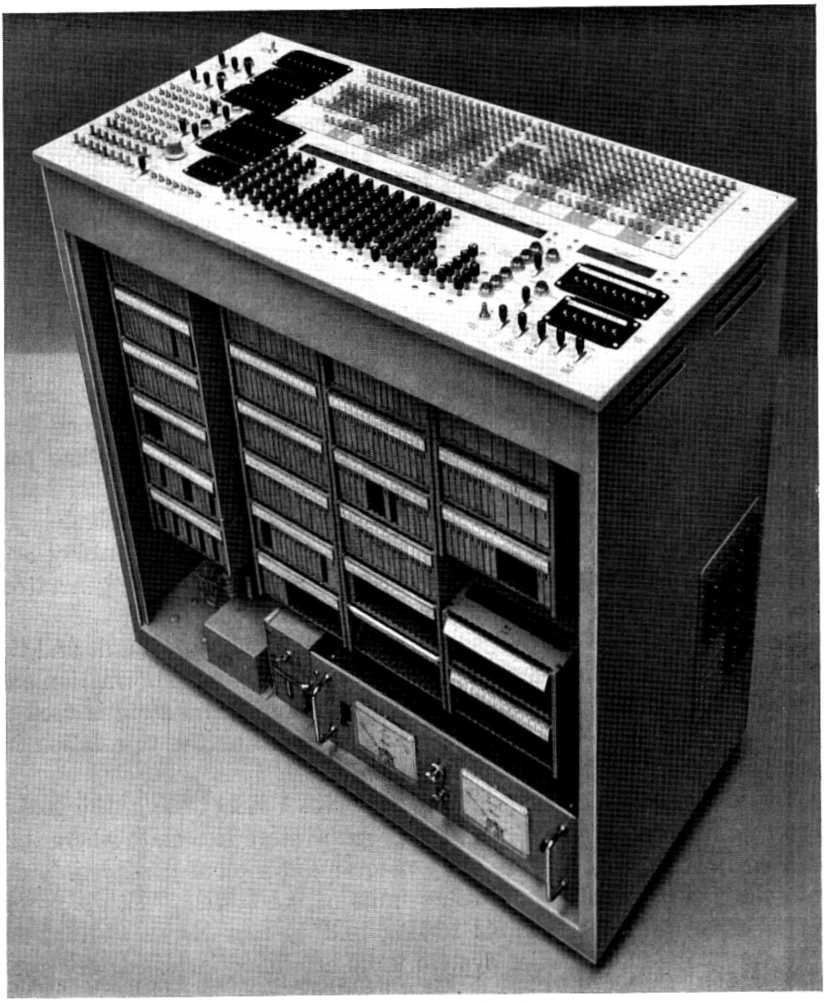

Fig. 2 — Central control manual tester.

this set one is able to

(1) insert instructions and control the execution of instructions by central control,

(2) simulate the response of any unit to central control,

(3) monitor key points in the central control,

(4) monitor outputs of the program store, call store and scanners, and

(5) generate signals to stop or interrupt[4] the system or automatically

insert program instructions when a selected program store or call store address is reached.

The last feature is used when a central control is under program control. In fact, the central control manual tester is the primary tool used with the X-ray programs.

2.2 *Programmed Hardware Testing*

The No. 1 ESS is a program-controlled machine having a high degree of control centralization. This made possible the use of programs, very powerful tools, for system testing. Also, because of the high degree of control centralization, common testing is emphasized. That is, once the central control operates with the program store, it is used to test itself and the rest of the system in a "bootstrap" manner.

The basic central control circuits are tested first. Using the basic central control functions, the central pulse distributor is tested next, and in the process additional central control functions are tested. In a similar manner, the call store and the peripheral units are added in turn. The unit to be tested is selected by switches on the central control manual tester.

The X-ray programs are designed to test at operating speed bit-by-bit and function-by-function a system which has not been previously operated. The underlying principle employed in the design of the X-ray programs is to start with simple tests to check out basic circuits, then gradually extend into other circuits using, insofar as possible, only previously tested circuits. Each test in the X-ray program checks for a known test result and is designed to check a particular circuit or function.

A generalized sequence chart for the X-ray programs is shown in Fig. 3. The programs go from test to succeeding test until a failure occurs. When this happens, a transfer is made to a failure leg. What happens in this leg is dependent upon the circuit-controlled option which has been selected by the user. These options are provided in the central control manual tester which is plugged into the system during the X-ray tests. The options are stop, record and advance, and recycle.

Stopping freezes the machine in a state as close as possible to the trouble condition. Pertinent information about the state of the system at the time the error occurred is preserved and displayed on the central control manual tester.

Record and advance is an attempt to save the data in the central control registers and continue. The data are typed out via a teletypewriter at the end of every test that fails.

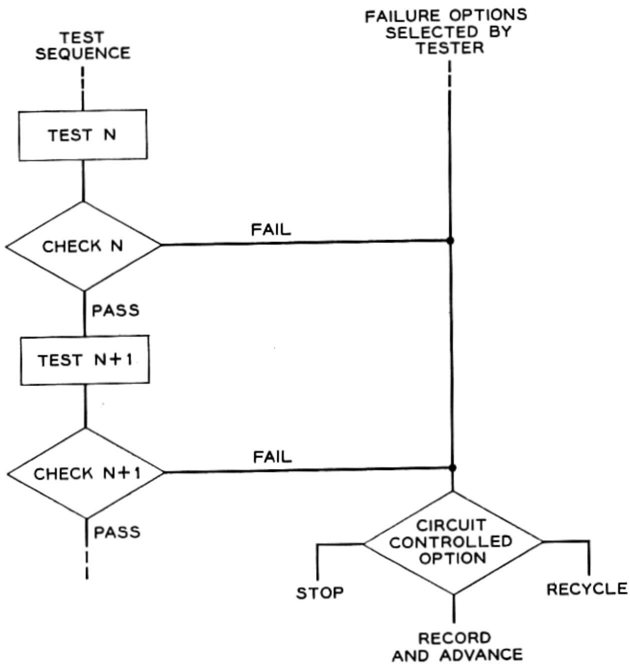

Fig. 3 — Generalized X-ray sequence.

Recycle provides a means to continually repeat the test at system speed. Therefore, any part of a circuit can be examined with an oscilloscope under dynamic conditions.

The normal mode of operation is to use the stop option to detect a trouble. With the machine stopped, lamps on the central control manual tester (J-register display)[4] are used to determine the program store address of the test which failed. For each test a comment indicating the possible source of trouble, should the test fail, is given in the program listing. Other lamp displays on the central control manual tester yield further information regarding the trouble. At this point the trouble is localized. Additional information about the trouble can be obtained by recycling the test. Using this procedure, which requires the use of the X-ray program listing, circuit schematics and the oscilloscope, a trouble is usually tracked down quickly.

The X-ray programs for most of the system units are divided into two parts, single system and duplicate system. A single-system X-ray is used to test a single unit. A duplicated system X-ray tests multiple-unit arrangements and maintenance features. All X-ray tests are made with a central control-program store combination.

For reliability and maintenance purposes[2] all units, with the exception of those which affect only single customers, are duplicated. The duplicated units normally run in parallel. Each is checked against its mate by match circuits while performing identical functions. It is possible, however, with minor hardware modifications, to split the system into two independent systems. Such an arrangement, using a central control manual tester on each system, has been used during single-system X-ray testing. This method of operation accelerates single-system X-ray testing, thereby reducing the hardware testing period. For duplicated system X-ray tests, the split system arrangement is not applicable.

The X-ray programs used prior to cutover and the maintenance programs used after cutover of an office to service are similar, since they both test the same hardware. In what follows, some of the factors which caused differences are discussed.

Maintenance programs have stringent real-time and complicated interface requirements because they must share real time with call programs. The X-ray programs, used before a system is providing telephone service, are not time-shared with call programs. In addition, the X-ray programs need not share the system memories with call programs.

The primary maintenance tool used when a No. 1 ESS is giving telephone service is the dictionary.[8] A maintenance dictionary is a table relating the printouts of diagnostic test results with corresponding faulty plug-in packages. The dictionary technique is built upon the assumption that a trouble has just occurred in a working system. However, at the outset of the hardware phase of system testing, multiple faults must be assumed in the system and the dictionary technique is not applicable.

The maintenance programs have available to them all of the hardware maintenance facilities — for example, working teletypewriters and match circuits. On the other hand, during much of the hardware phase of system testing the hardware maintenance facilities are not usable as tools.

The dictionary technique makes use of the pattern of test failures which results from a series of tests applied over large amounts of circuitry. The X-ray technique makes use of the information at the first test that fails in a series of tests, each of which is applied over small amounts of circuitry.

In Table I these factors are summarized. In the last column of the table an S or C indicates whether a factor results in simplification or complication in the design of the X-ray programs.

TABLE I — TEST PROGRAM COMPARISONS

Factor	X-Ray	Maintenance	Result
Time shared with call programs	no	yes	S
Memory shared with call programs	no	yes	S
Use of auxiliary test sets and instruments	yes	no	S
Multiple faults in every unit	yes	no	C
System maintenance facilities available	no	yes	C

The assignment of central pulse distributor, scanner, and signal distributor points varies from office to office. The X-ray program obtains the addresses of these points and other items which vary from office to office by reference to a translation area,[6] provided for system programs, in the program store. Thus the X-ray program is usable in any No. 1 ESS installation.

III. SOFTWARE TESTING

The large system program for No. 1 ESS is at least as complex as the hardware used to carry out the program. The early systems are being used for design debugging of the software as well as the hardware.

3.1 *Hardware Facilities*

During system testing of No. 1 ESS, input-output, control, and monitoring facilities, which can be used for program debugging, are provided by the central control manual tester and the system's maintenance teletypewriter, automatic message accounting magnetic tape unit, and control display and test unit. However, because of the large amount of program debugging being done at the Holmdel Laboratories, additional facilities were added to the Holmdel system to provide greater speed and flexibility.

The additional input-output facilities provided at Holmdel consist of a card reader, a high-speed printer and a magnetic tape unit.

A card reader, which reads 100 cards per minute, is used as an alternative to the teletypewriter to load information into the ESS. This means of loading information is a more reliable means of repeatedly introducing information than the teletypewriter, is more flexible and is about 10 times faster than teletypewriter tape. The information is read into the system via No. 1 ESS scanners. This reader has also been provided at Succasunna for use in program debugging.

A high-speed printer, which prints 80 characters per line at 1000 lines per minute, is used as an alternative to the teletypewriter to dump information from the ESS. It is more than 100 times faster than the teletypewriter. The printer provides a practical means of obtaining large amounts of data from the system without excessive use of machine time and eliminates the delay that is encountered in obtaining printed copy if magnetic tape is used. The system communicates with the printer via the peripheral bus.[3]

The tape reader assembler and processor (TRAP) is a facility used to control the transfer of data from magnetic tape to program store twistor cards via the memory card writer. TRAP has been provided at both the Holmdel and Succasunna installations because of the frequent changes required on twistor cards during the program debugging period. In addition, the TRAP unit at Holmdel has been modified and connected to the system's peripheral bus so that its magnetic tape unit can be used in loading and unloading system information. The magnetic tape unit is about 12 times faster than the high-speed printer.

At Holmdel a program test console (console) is used in place of a central control manual tester; it provides greatly expanded monitor and control facilities. In appearance, the most striking difference between these units (see Figs. 2 and 4) results from the 2544 monitor lamps on the console as opposed to a 442-lamp display on the central control manual tester. The console simultaneously monitors 864 points in each central control. These points include almost all of the central control flip-flops. The remaining lamps are used to monitor key points in all other units of the system. The view of system status provided by these lamps is especially important in debugging maintenance programs.

The console also provides three additional displays. A cathode ray tube display of the program flow is obtained by using a digital-to-analog converter on a program store address register. Because the No. 1 ESS is controlled by a repetitive executive control program, this display provides a picture which gives immediate indication of program response to external inputs and detection of anomalies in program flow.

For call stores, in which 24-bit words are stored, there are two console displays. One makes use of program control to display the contents of any set of 31 call store locations as a 31×24 array of spots on a cathode ray tube. Another circuit, not program-controlled, uses a bank of 24 lamps to provide a continuous display of the contents of any selected call store location.

The console and central control manual tester both provide similar control of the central control clock for stopping, manually stepping, and

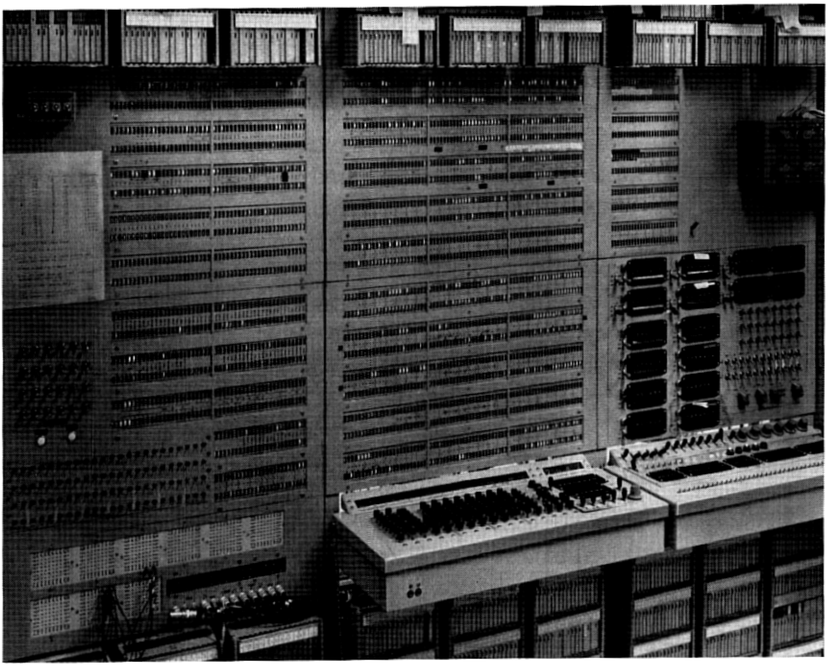

Fig. 4 — Program test console.

inserting simulated inputs. The console connects to all units of the duplicated system, while a central control manual tester can be connected to only a single central control. The console is capable of more fully controlling the duplicated system, as well as being able to control either half. In addition, the console provides manual control over many of the important maintenance features such as the inhibition of system interrupts.[4]

A simplified picture of program debugging closely parallels that of circuit debugging. Inputs are applied and outputs are checked. If trouble is suspected, internal conditions must be examined. To obtain easy access to information about any selected point in a program, flagging facilities are provided in the console and the central control manual tester. A flag is a signal generated under specified conditions which can be used to (a) stop the system, (b) light a lamp, or (c) interrupt the system. The console has provisions for generating fourteen distinct flags. The mechanisms for generating flags are:

(1) program address match — There are eight sets of switches on which program addresses can be set up. Whenever the central control

addresses the program store to an address which has been selected, a flag is generated.

(2) call store address match — There are four sets of switches used to select call store addresses in a manner similar to selecting program store addresses. In addition, reading or writing and/or a bit configuration for the data may be specified as additional conditions on the generation of flags.

(3) call store block match — There are two call store block match circuits identical to the call store address match circuits except that two sets of switches are provided with each circuit to define a range of addresses. The address condition for the flag is satisfied whenever a call store address is used which falls within a selected range.

3.2 *Programmed Facilities*

To expedite program debugging a programmed ESS utility system has been designed around the flag generators. The teletype or card reader is used to insert information into the system to define the function to be performed when a flag generator causes an interrupt. The function to be performed can be made up of any combination of the following:

(1) dump — The contents of call store or central control memory locations are written on the teletypewriter, high-speed printer, or TRAP magnetic tape.

(2) write — Information previously entered in the system (via card reader, teletypewriter or magnetic tape) is transferred into preselected call store or central control memory locations.

(3) trace — This sets up a central control mode which causes a dump to be performed at each program transfer.

Upon the completion of any of the above items, program control is transferred back to the point which was interrupted.

(4) jump — Jump specifies a program address to which control is transferred.

(5) patch — This causes the system to transfer program control to instructions which have been previously written in the call store.

The utility system outlined above was designed to be usable, with some restrictions, for program debugging using the central control manual tester. Most of the restrictions arise because the central control manual tester does not have any call store block match circuits and has only two program store and two call store address match circuits.

The program debugging facilities described were designed so that program test conditions could be submitted to the system and results obtained with a minimum expenditure of ESS machine time.

IV. OPERATIONAL TESTING

Operational testing verifies that the hardware and the system program satisfy system requirements. So as not to delay the introduction of a new system into service, this phase of testing must be started early enough to insure time to take corrective action as required.

The early systems must be subjected to extensive operational testing. These tests, among other things, must

(a) check all call features without and with traffic,
(b) verify traffic handling capability,
(c) verify traffic counts,
(d) verify AMA accuracy,
(e) check all maintenance features,
(f) evaluate maintenance dictionaries,
(g) check system capability at temperature and voltage limits, and
(h) check transmission and crosstalk characteristics.

At later installations these items will be tested, but much less extensively. In addition, installation tests include other items such as

(a) verify all translations (lines, trunks, etc.),
(b) test all lines, and
(c) test all trunk circuits.

V. EXPERIENCE

Fig. 5 presents a simplified picture of key events in the testing of the Holmdel system during the year 1963. The arrival times of the central controls (CC's) and the program stores (PS's) are shown. System testing did not really start until the receipt of program store 1. Prior to that time central control 1, which was shipped from the factory without benefit of factory testing, underwent extensive manual testing. The early manual tests were primarily of continuity, while later tests were functional, using program instructions inserted via the central control manual tester. Intervals for the wiring of major central control design changes are also indicated. The start of the use of X-ray programs, the beginning of system program debugging on one shift, and the expansion of this effort to two shifts as well as the first No. 1 ESS telephone call made using an X-ray program are also shown.

Fig. 6 presents a simplified picture of key events in the testing of the Succasunna system.

Figs. 7 and 8 show the total number of troubles cleared per month at Holmdel and Succasunna during 1963. They are broken down into three categories: wiring, circuit pack, and other troubles.

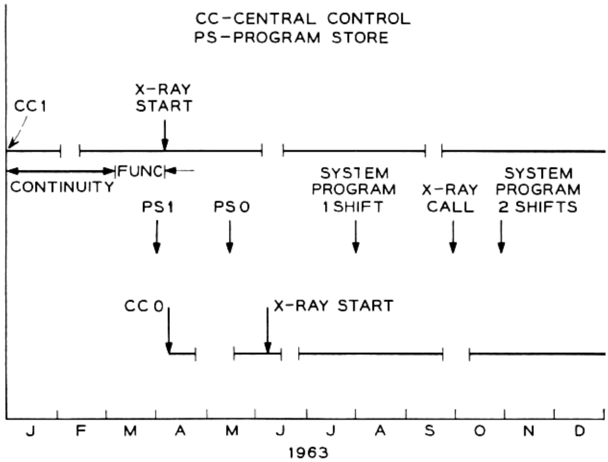

Fig. 5 — Holmdel system events.

Circuit pack troubles were running about 35 a month on the Holmdel system and somewhat higher than this at Succasunna at the end of 1963. There are approximately 11,500 circuit packs in each of the systems. Experience with the Morris ESS[7] and other electronic systems indicates that an order-of-magnitude reduction can be expected in the package failure rate as an electronic system moves from the testing and wiring change period into service.

Many of the earlier wiring troubles encountered at Holmdel were attributable to the factory. A lower proportion of the wiring troubles at

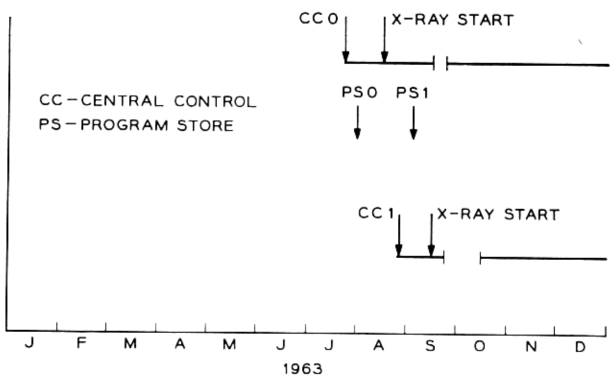

Fig. 6 — Succasunna system events.

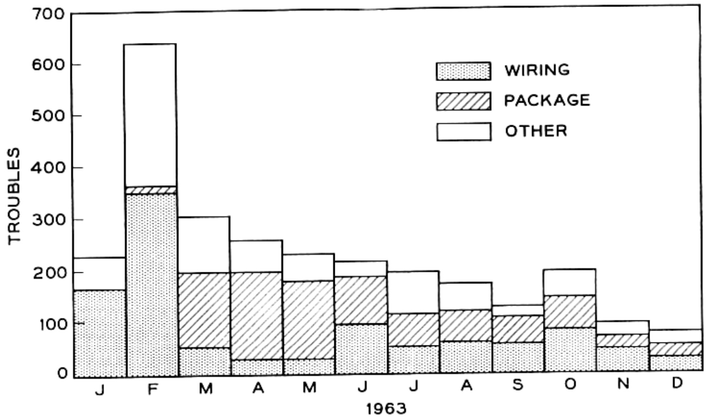

Fig. 7 — Troubles cleared per month at Holmdel.

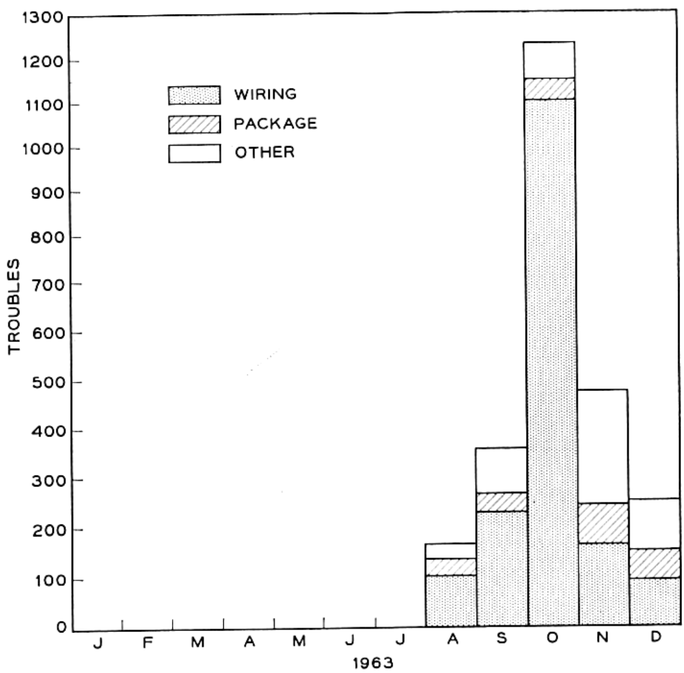

Fig. 8 — Troubles cleared per month at Succasunna.

Succasunna are attributable to the factory. They, like the later wiring troubles at Holmdel, are more frequently chargeable to installation and design change wiring.

Included in the category of other troubles are logic and circuit design problems uncovered in system testing. This source has been a major contributor to design changes necessary to realize an operational system.

The principal sources of program problems are programming error, clerical error, requirement change and program improvement. Fig. 9 shows the number of program problems encountered per month on the Holmdel system during 1963. These were found and corrected while debugging X-ray and system programs. Since Holmdel is the first No. 1 ESS, it was necessary to do much of this work, particularly the debugging of X-ray programs, concurrently with the debugging of the hardware. On the average, one program problem was cleared for every 55 program words verified.

System testing using X-ray programs read from program stores began at Holmdel on April 5, 1963 (see Fig. 5) and at Succasunna on August 16, 1963 (see Fig. 6). This work was carried out on a two- and three-shift basis at both places. Fig. 10 gives the number of troubles cleared per shift-month at Holmdel and Succasunna and makes a comparison by referencing them to the month in which X-ray testing started at each location. As can be seen, troubles were found at a faster rate at Succasunna than at Holmdel. The major reason for this is that testing on the Succasunna system made use of X-ray programs that had already been debugged on the Holmdel system.

The size of a system hardware testing task is dependent not only on the number of system units involved but also on their complexity. Complex units have larger X-ray programs associated with them than less complex units. This suggests better ways of measuring the size of a system hardware testing task than merely totaling the number of units in-

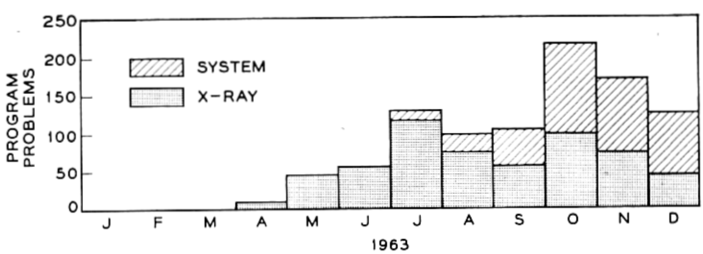

Fig. 9 — Program problems encountered per month on the Holmdel system.

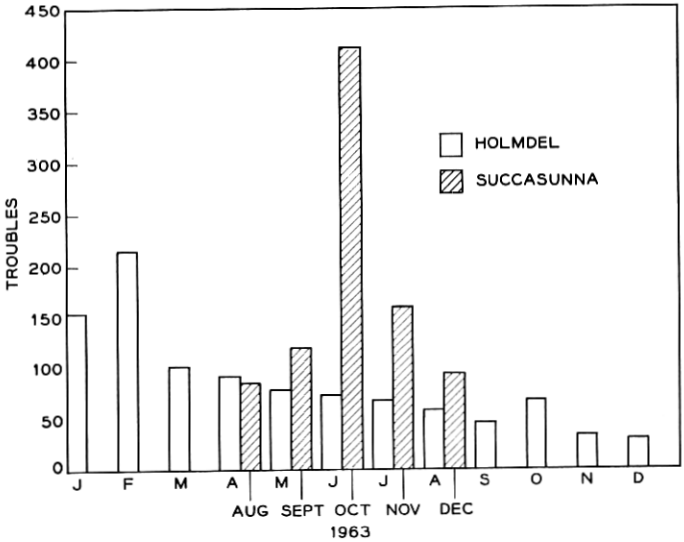

Fig. 10 — Troubles cleared per shift-month at Holmdel and Succasunna.

volved. A more meaningful and easy-to-use measurement is the sum of the products of the number of units and the number of associated X-ray program words, unit-words. This concept is illustrated for several No. 1 ESS units in Table II.

Using cumulative unit-words per shift, a comparison of the initial progress at Holmdel and Succasunna is given in Fig. 11. The solid-line curves show the progress by actual date. The dashed-line curve references the progress at Succasunna to the Holmdel X-ray start date. The more rapid progress at Succasunna was made possible by the use of debugged X-ray programs and by the absence of troubles common to both systems that had already been cleared at Holmdel.

Fig. 12 is a plot of the progress made in debugging X-ray programs concurrent with their use in debugging the Holmdel system hardware. As can be seen, the verification of these programs was nearing completion

Table II — Unit-Words for Representative Units at Succasunna

Unit	Number	Words/Unit	Unit-Words
Central control	2	19,100	38,200
Central pulse distributor	2	840	1,680
Call store	4	3,750	15,000
Master scanner	2	1,120	2,240

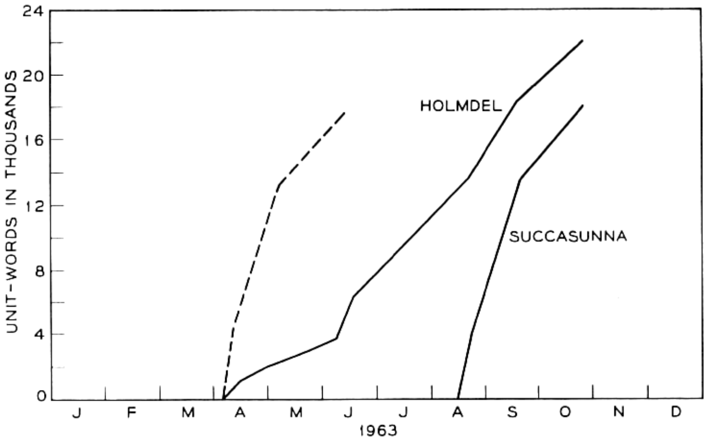

Fig. 11 — Cumulative unit-words per shift at Holmdel and Succasunna.

at the end of 1963. Also shown is the early experience in debugging system and utility (see Section III) programs. By using the data given in this figure and the dates on which system program debugging started as a one-shift and later two-shift operation (see Fig. 5), it can be calculated that an average rate of 2000 words per shift-month was realized.

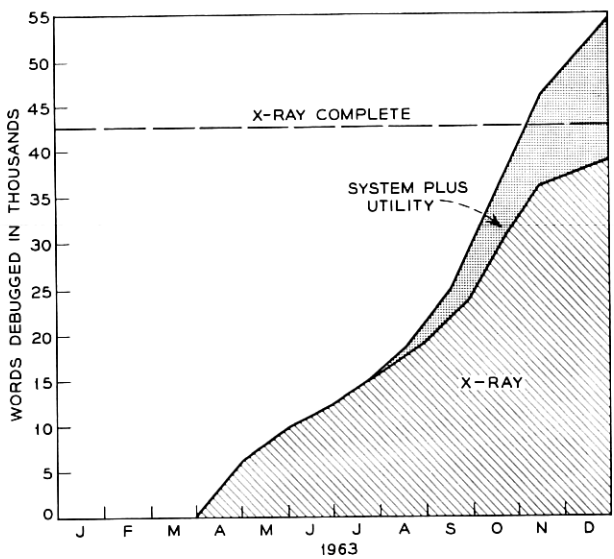

Fig. 12 — Program debugging progress on the Holmdel system.

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