No. 1 ESS ADF:

System Testing and Early Field Operation Experience

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This article describes the equipment and test procedures used for system testing of a large store and forward system. It discusses a novel programmed computer load test facility for determining system operational characteristics in overload, system traffic handling capacity, and the adequacy of operational call register design. It presents early field experience with No. 1 ESS ADF controlling a very large nationwide data network for the Long Lines Department.

I. INTRODUCTION

A No. 1 Electronic Switching System Arranged with Data Features (No. 1 ESS ADF) was installed in New York City to operate and control the Long Lines Department's nationwide Administrative-Data Network (ADNet).[1] The new system was cut into service February 3, 1969, and connects some 720 Long Lines, Operating Company, and Western Electric Company locations to the No. 1 ESS ADF switching center through 400 circuits which are terminated by 1,250 four-row teletypewriters that use the American Standard Code for Information Interchange (ASCII). Connection is also made to computers at two Long Lines data processing centers so that computer-generated data can be distributed by the network, or field data can be assembled for computer center processing.

Large traffic handling capacity was needed for the ADNet. Therefore, a near maximum-sized system has been installed. Two autonomous data scanner-distributors terminate 1,024 full duplex or half duplex data lines which operate at speeds up to 150 words per minute. Call stores capable of handling 159,744 24-bit words, duplicated, are provided. Duplicated program stores of 327,680 44-bit words are provided for storing the 250,000 word program, along with translation and parameter data for 1,024 lines.

Two duplicated disk communities, each capable of storing 2,359,296 24-bit words, are used for in-transit storage. There are 12 magnetic tape units, so that journal filing, permanent filing, and retrieval can be handled with six tape units in the on-line pool for retrieval. This provides an on-line retrieval capacity of approximately 75,000 messages.

The various development testing phases of a message switching system of this complexity added up to a sizable undertaking. New testing techniques were developed to yield thorough hardware and software testing in minimum time.

II. FUNCTION TESTING

When testing any large system, it has been conventional to divide the work into two main phases, discrete function testing, and system operation and maintenance testing. However, it is quite difficult to define exactly where function testing for either hardware or software ceases and system testing starts. This article uses a somewhat arbitrarily-defined point: that point where all program words had been initially debugged (see Fig. 1) and all hardware testing had been completed in a fashion similar to a conventional No. 1 ESS system.[2] Hardware testing is not described here. Function and system tests are separated to present certain of the testing phases which were somewhat uniquely handled in the overall testing program.

The complete computer program required by the No. 1 ESS ADF system contains about 250,000 words. A considerable amount of program testing was required over a period of three years before the system was considered to be operating satisfactorily. The bulk of the testing was performed in the test model system laboratory at Bell Telephone Laboratories, Naperville, Illinois. The function testing required 22 months while system tests started seven months before system cutover and continued for eight months after. The progress in program testing, indicated by the amount of program words debugged during this period, is shown in Fig. 1.

During function testing the individual programs were tested as independently of other system functions as possible. A test plan was devised that would achieve the maximum (*i*) rate of program integration, (*ii*) number of programmers able to use the system effectively, and (*iii*) number of programmers on day shift. To implement this

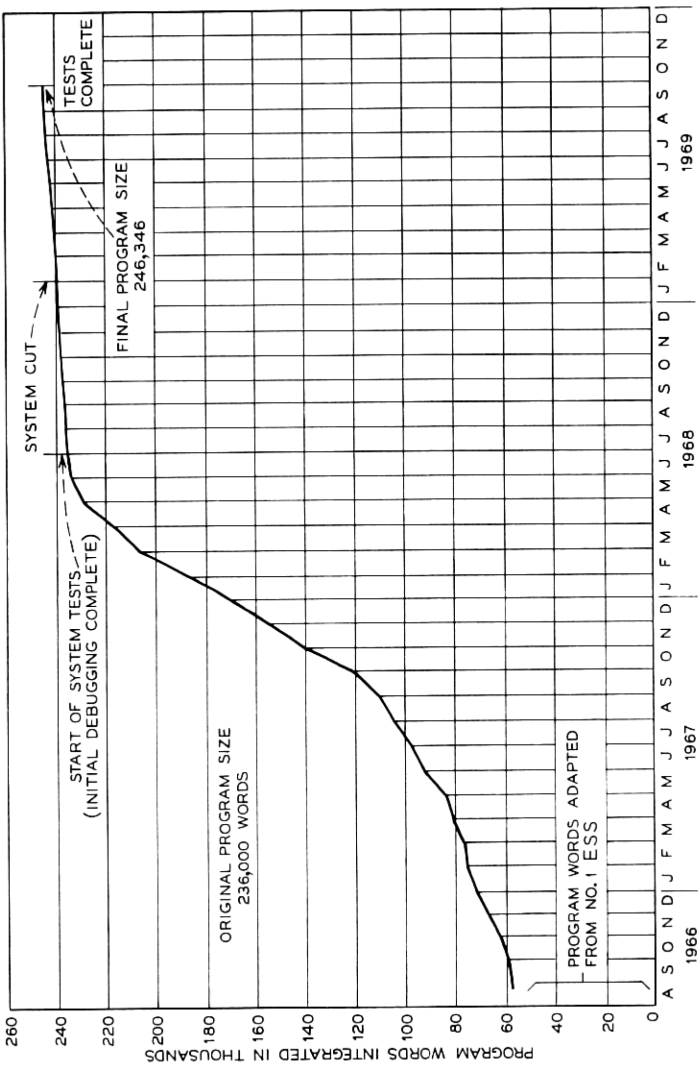

Fig. 1—No. 1 ESS ADF program integration.

plan, special utility programs were developed, new laboratory operating procedures were established, and a new program test console was designed. The console, as shown in Fig. 2, contained some 6,000 lamps indicating status in all parts of the system and the information stored in the many system registers. It was an expansion of previous ESS test console designs with their capabilities, but several important new features were added.[2] Facilities were installed for controlling and monitoring the frames unique to No. 1 ESS ADF, along with additional program and call store address matchers which could be set electronically under program control from card input data. The entire console was duplicated, but so interconnected that a duplex system could be controlled from either half, or the system could be split into two simplex systems each independently controlled by one half of the console and each half capable of independent operation. This feature doubled the machine testing capacity for those programs not requiring a duplex system.

The general concept for the plan of operation was to run the system laboratory as a computation center where programmers would work on a single day shift while there would be sufficient console operators to complete all the day's batch work in either two or three shifts, as required. A programmer could request to be present while his work was being run, to observe the system operation and make limited changes in his test procedure. All work, however, was under control of the console operator. No time was allowed for problem study at the machine, on machine time. All problem study was done off-line with only completely defined tests being run using machine time.

If a programmer were not present, his work was called a "batch" run. If he were present, his work was called a "personal" run. No time limit was placed on the length of batch runs, but the longer runs were usually performed during night shifts. However, a personal run was limited to ten minutes because experience showed that few programmers could efficiently use more than ten minutes of time on a personal run without requiring at least one-half hour off-line time to analyze his results.

This general plan was adhered to during the period of function testing and well into the system test period. During the end of the system test period before cutover, the request for batch runs dropped off and the personal run time was allowed to become longer. After the New York system cutover the work became almost entirely personal runs with the run time limit extended to 30 minutes.

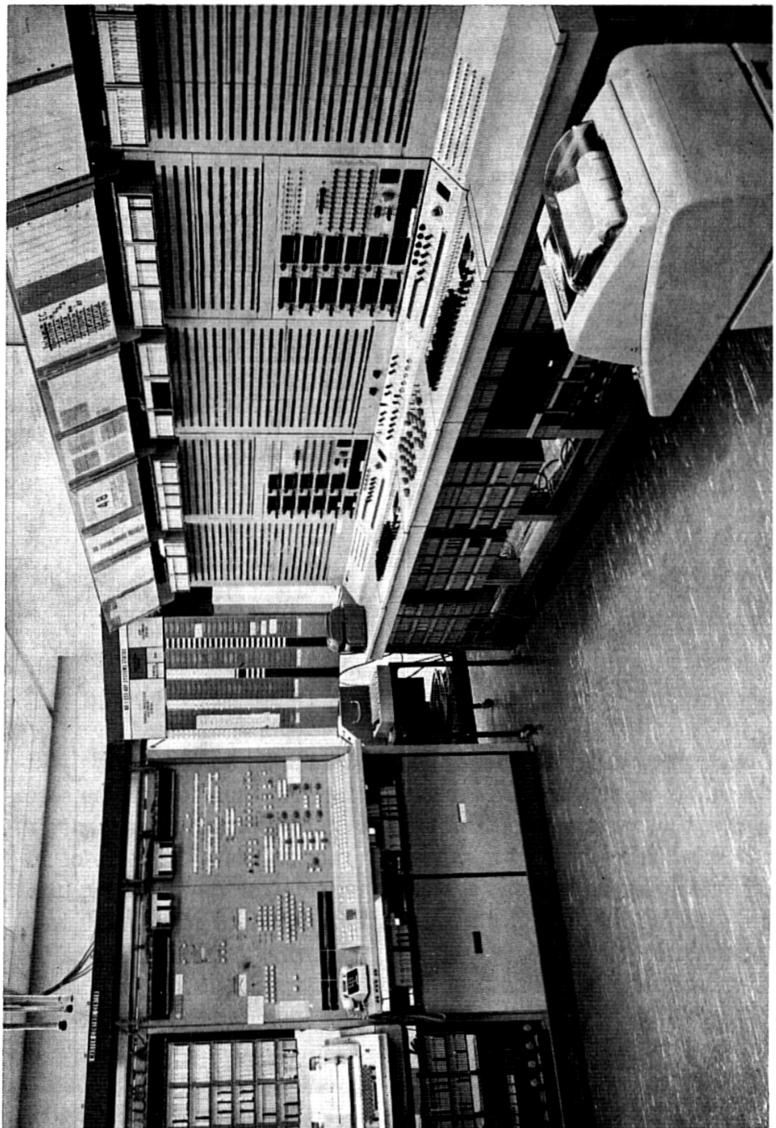

Fig. 2—No. 1 ESS ADF test control area.

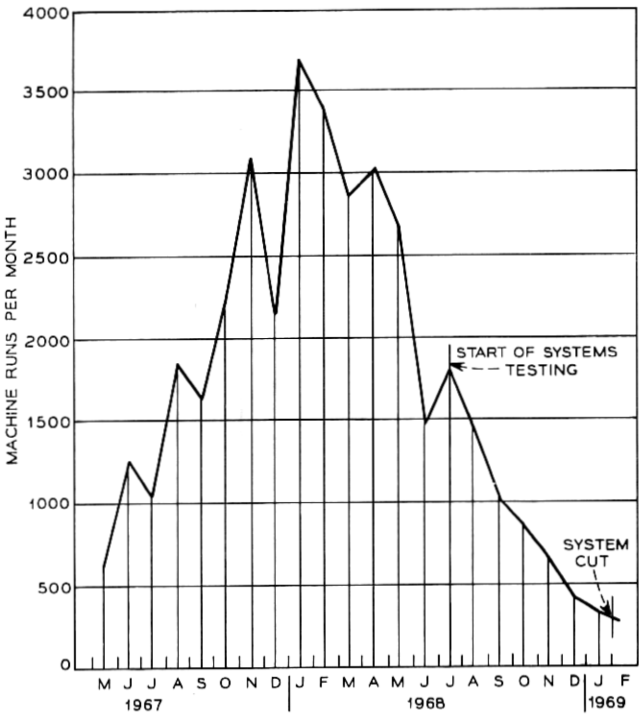

Fig. 3—Total batch and personal test runs per month.

At the start of program testing on a test model at Naperville, Illinois, not all the programs had been loaded. As more programs were loaded into the system, the quantity of test runs increased sharply. Figure 3 shows the total runs made per month from the start of integration until the New York system was cut over in February 1969.

Figure 4 shows the monthly percentage of the total runs which were batch runs during the entire test period. During the debugging of individual programs the percentage of batch runs was high, but as the testing became more of the system type, the percentage dropped off.

Figure 5 shows the average length of a test problem. The length of each test during the peak program debugging months was kept under five minutes. Of this, set-up and read-in of the instruction deck took less than one minute, the run itself averaged two minutes, and the high-speed printer dump used the remaining time. With the dual input console arrangement, the tests were made alternately on each half

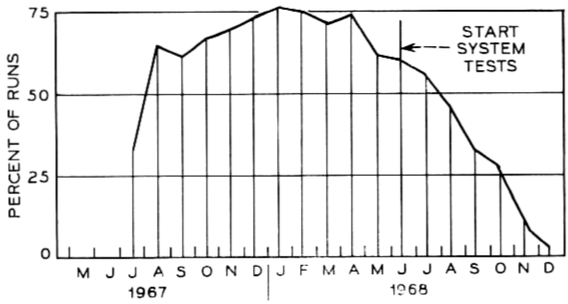

Fig. 4—Percent of batch runs to total runs.

with one half setting up the next run while the other half was making a run. This feature greatly helped to keep running time to a minimum.

Figure 6 shows the monthly rate of program integration which reaches a peak of over 18,000 words in a month. Figure 7 shows the relationship between words integrated and tests made. The relationship remained relatively constant throughout most of the integration period, indicating that a definite number of test runs must be made by a programmer to accomplish a given amount of program integration. This seems to be independent of the length of run or the work load being performed in the laboratory.

The relationship between the number of program words integrated and hours of machine time is shown in Fig. 8. The overall average was 37 words integrated per hour of machine time based on the hours when the machine was used only for program debugging. If all the hours of machine time, that is, overwrite time and maintenance time, are included, the average number of program words integrated per hour drops to 30.

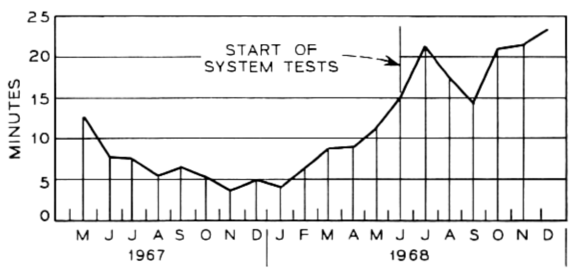

Fig. 5—Average length of run.

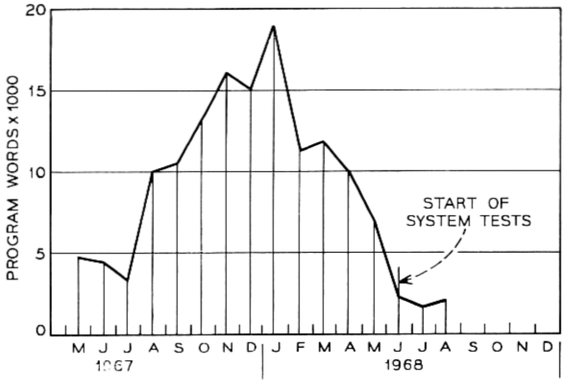

Fig. 6—Program words integrated per month.

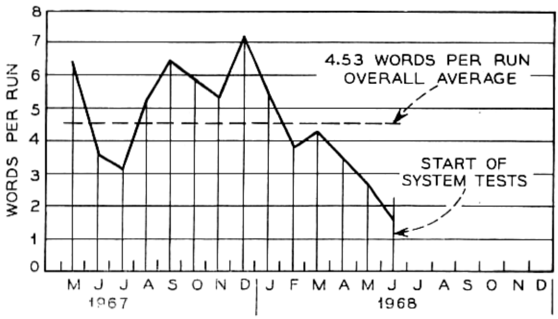

Fig. 7—Program words integrated per run.

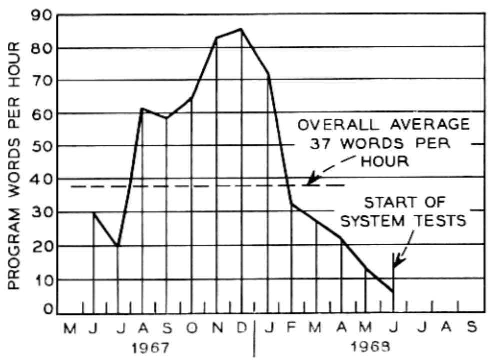

Fig. 8—Program words integrated per hour of machine time.

During the various phases of program testing at the Naperville Laboratory, 58,000 overwrite words of program were introduced while debugging 134,000 words of program. During the seven months of system testing, 22,000 overwrite words were made against the whole program of 242,000 words, that is, 9.4 percent of the program was changed. During the first eight-month period after system cutover, 9,700 overwrite words have been put into the system, many because of feature additions. Detailed information on the number of overwrites made is shown on Figs. 9 and 10.

III. SYSTEM TESTING

System testing was conducted primarily on the New York installation of the No. 1 ESS ADF system. This installation alone contained a full complement of hardware necessary to operate the system at full design capacity and to provide a nearly normal environment for testing operating procedures. This testing period started seven months

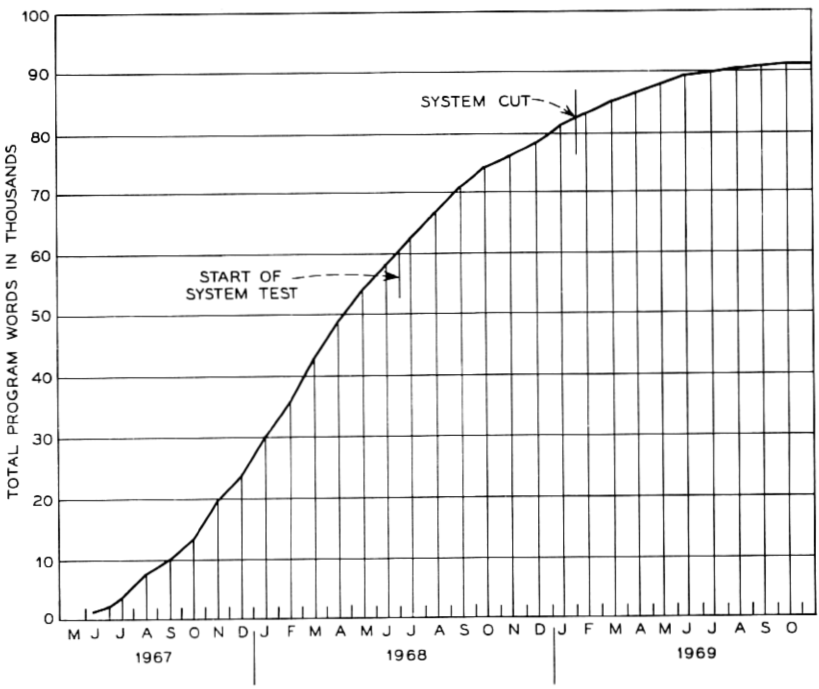

Fig. 9—Total overwrites installed in Indian Hill system during testing.

before cutover and continued for eight months after. The system tests consisted of three distinct but related areas of testing: feature tests, network tests, and load tests.

3.1 *Feature Testing*

A detailed test plan was prepared before the start of system testing. This plan listed all the tests to be conducted and the system conditions and configuration for each test. The tests included all operational and administrative features, maintenance test procedures, and system responses to abnormal conditions.

A test bed of stations, not part of the Long Lines network, were connected to the New York system for operational feature testing. This group of stations consisted of six eight-level ASCII stations and nine five-level Baudot stations. There were approximately 500 operational tests subdivided into major feature categories as shown in Table I. Each test required the preparation of station message tapes; and because of the limited number of stations in the test bed, recent change tapes had to be prepared for many of the tests to establish the proper station options for the given test. Several general purpose programs were written to aid in the preparation of these test tapes.

These tests were systematically run during the early months of the system test and were very effective in detecting program bugs. Many of the tests were performed while a large system load was being placed on the system by the load facilities which are discussed in Section 3.3. A subset of these tests were used until cutover to test the introduction of new program loads in the New York system.

3.2 *Network Testing*

During the seven months before the cutover the 400 circuits and approximately 1250 teletypewriters were installed and tested from manual

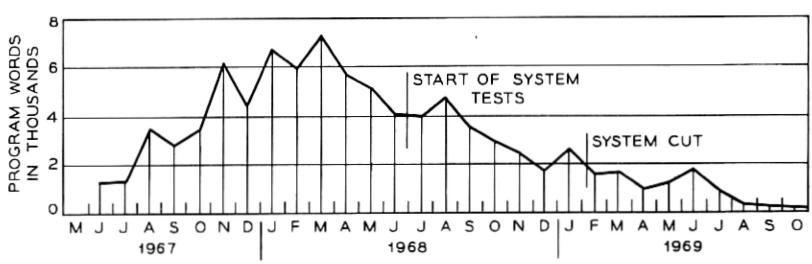

Fig. 10—Overwrite words installed per month.

TABLE I—OPERATIONAL FEATURE TESTS

Heading format	133
Addressing	8
Precedence	30
Privacy	4
Multiline hunt group	15
Message retrieval	48
Poll-delivering criteria	111
Undeliverable traffic	17
Miscellaneous customer services	126
Total	492

transmission test positions. Five months prior to cutover, the translation data for the total Long Lines network was installed in the New York system. During this period, one shift of system time was devoted to network testing which checked the ability of each station to transmit and receive traffic, and which verified the translation data. Message tapes were prepared by Bell Laboratories and mailed to station attendants for testing the transmission capability of each station. In addition, message tapes were prepared for a Long Lines location to send to each station for testing that station's receiving capability. Since stations continued to be installed throughout this period, special network testing programs and procedures were developed to allow the translation data to be progressively activated as the stations were installed.

These tests proved to be very effective, and the smooth cutover of the network was a direct result of the joint efforts and cooperation of Long Lines and Bell Laboratories personnel during this test period. The network tests also provided a vehicle for testing the No. 1 ESS ADF switching center. Any troubles reported during the tests were given the bookkeeping name of failure reports, and corrections were introduced into the program. Figure 11 shows the number of failure reports issued during system testing. Prior to cutover, there were 690 reports per month. While the network tests were responsible for a large number of these failure reports, load tests and feature tests which were conducted concurrently and the continued testing on the Naperville test model contributed significantly to these results. After cutover the rate dropped to an average of 135 reports per month for the next five months and then dropped to near zero. These failure reports were divided into three classes:

Class A, serious service-affecting troubles which were corrected immediately (less than five percent).

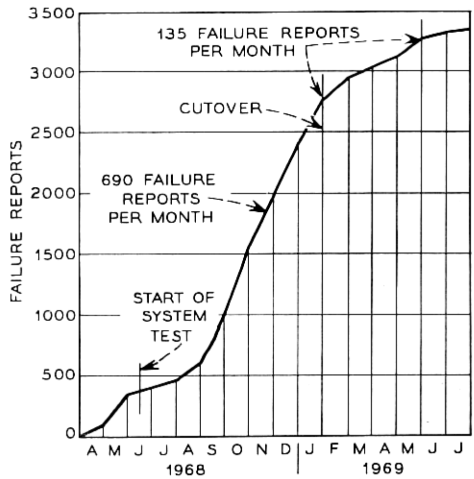

Fig. 11—Total number of failure reports.

Class B, refinements to service or maintenance which were corrected more routinely (over 80 percent).

Class C, corrected only if simple, otherwise deferred for later program versions.

3.3 *Load Testing*

A switching system cannot be considered to be fully tested until it is stressed to the limits of its traffic handling capability. However, the large traffic capacity of the No. 1 ESS ADF switching center makes live load testing difficult because of the problem of generating the large amounts of controlled traffic required to stress the system to capacity. To fully load the system with traffic on each line is impractical because the total cost of hardware becomes prohibitively great. Even if one could afford the hardware, it is virtually impossible to administer the generation of traffic to produce a controlled load which is reproducible. Therefore, load testing of the No. 1 ESS ADF system was accomplished through the use of two load boxes which were developed for this purpose. The test configuration for the load boxes, a five-level load box and a computer-controlled load box, is shown in Fig. 12.

3.3.1 *Five-Level Load Box*

The five-level load box was designed as a means of testing the data scanner distributor units under full load. This device consisted of ten paper tape readers each of which could be connected to as many as 52 ports on the data scanner distributor units. The load box thus simulated 520 five-level full duplex stations. The five-level full duplex signalling sequence is such that after the initial handshaking with the station to establish the connection, a multimessage transmission can be continued indefinitely since no further signaling dialogue between the station and the switching center is required. The control teletypewriter shown in Fig. 12 was used to handle the initial signaling sequences for each of the paper tape readers. Once the connection was established, the control teletypewriter was then available for use with another tape reader. While this load box arrangement was designed primarily for testing the data scanner distributor units, it had some characteristics which produced useful program tests. Since a paper tape reader was connected to 52 lines, the traffic presented to these lines was not random, that is, all actions such as start and end of message occurred simultaneously. This in turn produced stresses on particular program functions as each action occurred. This load box was an effective testing device in the early stages of system testing, but had to be removed when the network tests started to make way for the Long Lines network.

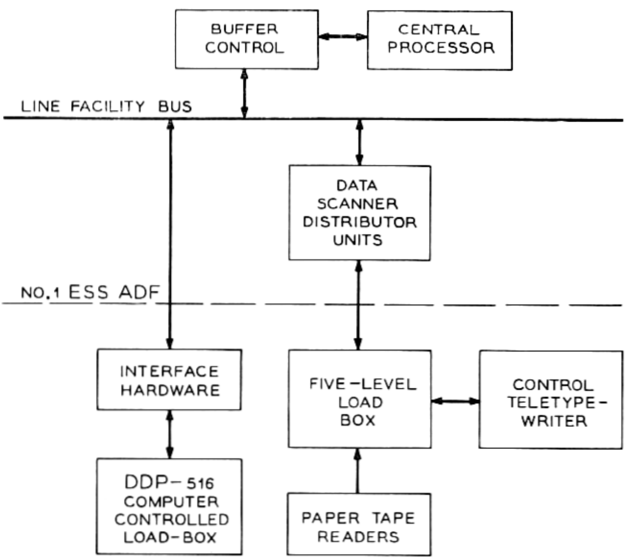

Fig. 12—Load box facilities used in testing the No. 1 ESS ADF system.

3.3.2 *Computer-Controlled Load Box*

A computer-controlled load test facility was developed for the No. 1 ESS ADF project. This load box consisted of a small computer, the Honeywell DDP-516, and hardware connecting it to the ADF system in such a way as to simulate a data scanner distributor unit with 512 lines and two stations per line. The program written for the DDP-516 computer provides a large degree of flexibility in controlling the traffic parameters used to specify the type of traffic load presented to the system.

These parameters are: (*i*) the number of active originating stations, (*ii*) the level of presented load called message presentation rate, (*iii*) the multiple address factor or number of addresses per message, and (*iv*) the text length of the message. The latter three parameters can be provided with constant, normal, or exponential distribution. Traffic statistics collected by the load box are periodically printed and have proven to be valuable in evaluating the No. 1 ESS ADF system operation.

The DDP-516 computer was so programmed that steady state or dynamic load testing could be performed. In a steady state test, the traffic parameters remain fixed during the test. This allows the system response to a steady load to be observed. In a dynamic test, the basic traffic parameters for the load box are varied with time according to a pattern. This allows the system response to varying traffic conditions to be observed.

The first use of the load box was to supply a background load while feature tests were performed on the system. Subjecting the No. 1 ESS ADF to traffic loads while making discrete functional tests of individual programs exposed program faults which otherwise would have remained undetected. Many of the program faults consisted of subtle interactions within the program which had a very low probability of occurring under light load. Such situations could be created by large volumns of traffic which would never have been produced manually. The ability to control the traffic and reproduce the tests made it possible to examine a given fault repeatedly.

3.3.3 *System Capacity Tests*

To build a foundation for future traffic engineering of the Long Lines network, it was necessary to make dynamic system load tests to gather information concerning the capacity limits of the system. In addition, system performance under heavy loads and overloads needed to be demonstrated. Since the system is now only partially loaded from the Long Lines network, the use of the computer-controlled load box was the only means of obtaining the desired test results.

The large number of system problems encountered before cutover and in the early months after cutover, and indicated in Fig. 11, made it impossible to perform meaningful capacity tests. However, these problems were gradually fixed and by September 1969, all the known software and hardware problems had been eliminated. A week-long test of system capacity and overload performance was conducted during September 1969.

The No. 1 ESS ADF system uses the time required by the program to complete the main program cycle (called the E-to-E cycle time) as a measure of the load on the system and as a means of initiating load control procedures. To aid in collecting data on real-time capacity tests of the system, additional measuring equipment was provided with the load box. This consisted of an electronic counter which was triggered upon the completion of each main program cycle of the No. 1 ESS ADF processor. The counter was started on odd pulses and stopped on even pulses. The results of the counter were read by the load box, thus the load box collected measurements of every other main program cycle time. These data were printed periodically as a part of the load box traffic statistics with the maximum, the minimum, and the average main program cycle time for the preceding period.

The load box also predicted the capacity based on measurements taken in the preceding measurement period. The prediction was an estimate of 90 percent of the limiting capacity, that is, 90 percent of the capacity at which the E-to-E cycle time would be infinite. The 90 percent level was chosen as the best guess of the level of capacity which would be achieved with the current load control parameters. The prediction was based on this equation which was derived from theoretical analysis of the system capacity.

$$C(0.9) = \frac{0.9E_AT}{E_A - E_N} \tag{1}$$

where:

$C(0.9)$ = 90 percent of the limiting capacity in characters per second.

E_A = Average E-to-E cycle time in ms.

E_N = No load E-to-E cycle time in ms.

T = Average capacity in characters per second during the measuring interval.

For some values of traffic characteristics, call store size and not real time, limits the system capacity; thus a prediction method was necessary to determine real-time capacity. Also, the load box prediction was useful during load box runs to establish changes in the input load box parameters to establish the desired load level. The data required for the calculation of equation (1) was measured by the load box during each test interval with the exception of E_N, the no load E-to-E cycle time. This quantity which was an input parameter to the load box was a constant for the purpose of the prediction calculation. The value used was the average E-to-E cycle time observed during long periods of operation with no load on the system and was about 50 ms. The variation in E_N during the test runs results in a prediction error in the calculation of equation (1). The value of the error decreases as the load increases and has been observed to be less than 3 percent for values of the capacity in excess of 50 percent of the real-time capacity.

The real-time capacity of the ADF system is a function of multiple address factor, message length, and statistical distribution of message length. Past estimates of capacity based on calculations rather than on measurements have indicated that the multiple address factor (M), the number of addresses per message, has a minor effect on capacity. To validate this, tests were made with $M = 2$ and $M = 3$ for the same average message length. The results indicated only a 5 percent increase in capacity for the higher multiple address factor. This confirmed the original assumption so that the major effort was directed at determining real-time capacity as a function of message length and its statistical distribution, and all other tests were made with a multiple address factor of 2.

Two test runs, fixed message length and exponential distribution of message length, were made for four average message lengths: 100, 500, 900, and 1,300 characters. The call store rather than real time was found to be the limiting factor on capacity for all average message lengths greater than about 300 characters. The call stores could support more capacity if the data rate on the lines were increased. For this reason, the load box was programmed to produce a line rate of 150 words per minute rather than the normal 100 words per minute for the tests made at the three longer message lengths. A load was applied to the system and allowed to stabilize. Recordings of capacity, predicted capacity, and minimum, maximum, and average E-to-E cycle were taken. The load was increased and the process repeated

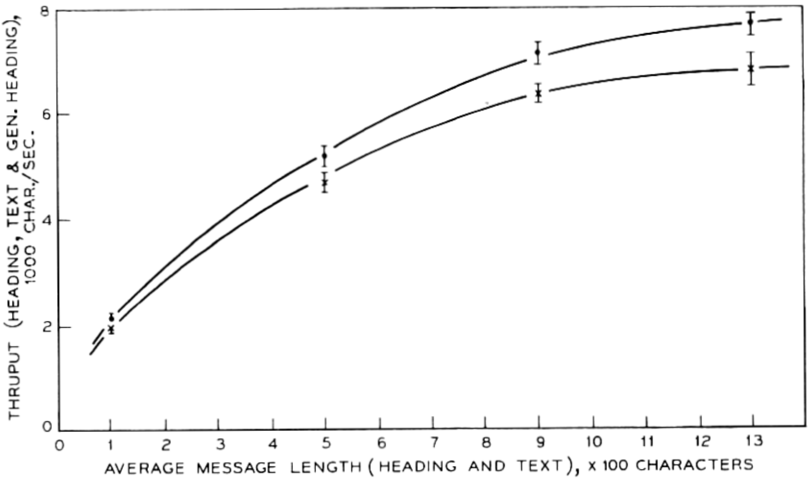

Fig. 13—Real time average and limits of capacity measurements for (●) fixed message length and for (×) exponential distribution of message length. The multiple address factor is 2.0.

until the real-time load control level was reached or the call store limited further increased in the load.

The predicted capacity, 90 percent of the limiting capacity, as a function of the average message length for the two types of message distributions, is given in Fig. 13. The prediction error should be low since capacity levels of 75 percent or higher were reached during each test run.

The tests were analyzed to determine whether the ADF system could operate at 90 percent capacity and, even further, whether it should. To understand this analysis, it is necessary to consider the functional relationship between the average E-to-E cycle time and the capacity, and how the capacity is limited by the load control parameters. The functional relationship between the average E-to-E cycle time and the capacity is a family of curves dependent on message length which tends to make the present considerations quite complex. To simplify the analysis, only the functional relationship between the average E-to-E cycle time and normalized load were considered, where normalized load is defined as the ratio of the amount of data that pass through the machine to the limiting capacity. This results in a single curve independent of message length. This relationship is given in Fig. 14 based on the load box data. At the load con-

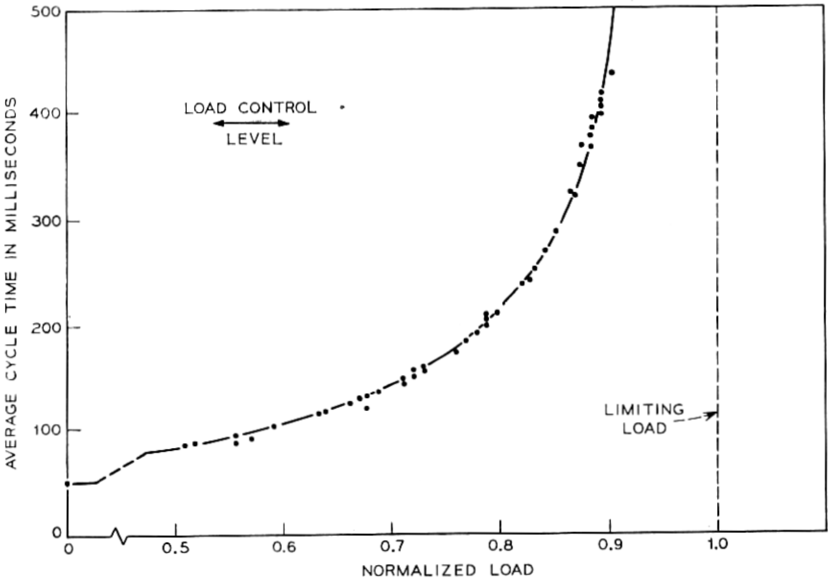

Fig. 14—Average E-to-E cycle time versus normalized load (ratio of data passing through the computer to its limiting capacity).

trol level, currently set in parameters as 400 ms, the capacity is kept by the load control procedures to approximately 88 percent of the limiting capacity, not quite 90 percent.

To determine if the load control level is set properly, the effects of peak rather than average E-to-E cycle time must be considered as two other actions are initiated as a result of parameter value comparisons with E-to-E cycle time. (*i*) If the E-to-E cycle time exceeds 3.24 seconds, a real-time overload will be declared and certain operational tasks will be suspended. (*ii*) If the E-to-E cycle time exceeds 4.32 seconds, phases of emergency action will be initiated.

During tests with the capacity at 85 to 90 percent, peak values of E-to-E cycle time went very high—about eight times the average E-to-E cycle time. However, the number of occurrences of real-time overload was small and it appeared that the recovery was rapid, that is, the real-time overload ended in the E-to-E cycle following the one in which it began. The overload appeared to have no effect on service; thus the current value of 400 ms for the load control level appears to be quite reasonable. With this control level, the system will operate at about 88 percent of the limiting capacity. The capacity curve of

Fig. 13 for the exponential distribution of message length appears to be a conservative representation of the real-time capacity of the ADF system for the Long Lines traffic characteristics.

To further confirm this conclusion, a load test of the No. 1 ESS ADF system was made during a normal traffic day. Throughout the test period, 8:00 a.m. to 6:00 p.m., the traffic data produced by the system was monitored. The load box parameters were adjusted to maintain a system traffic intensity that was three times that produced by the Long Lines network alone while maintaining the traffic profile, that is, the length of busy hours was unchanged. During the course of this demonstration, all the traffic was handled without an overload, although some of the call store facilities were in very heavy use. Toward the middle of the afternoon, it was decided that an overload should be forced on the system. Therefore, the load box traffic was sharply increased to force a call store overload. Load control was automatically called in and, after the overload was removed, the system recovered from the overload without incident or loss of messages. This test was a demonstration to establish performance credibility and was not used to collect capacity data.

3.3.4 *Queueing Tests*

A series of tests was designed to show that the queueing logic, imbedded throughout the operational program, operated properly for each and every call store facility. A method was devised, using a small number of program store overwrites, to artificially reduce the number of items assigned to any given call store facility. For the call store facility under test, the number of items available could be controlled and changed by setting the appropriate value in a call store location. With the load box providing a high level of load on the system, but with the load controlled to a level that produced no facility queueing, the number of items for the facility under test was reduced to where virtually continuous queueing existed. The system was operated for approximately one hour in this state to exercise as many points as possible in the program which involved queueing for the facility being tested. Audits were run periodically to detect errors, and the performance of the system was monitored. It should be obvious that there is no assurance that all points in the program which involve queueing will be tested by this process; however, those with a reasonable probability of occurrence will have been thoroughly exercised. All call store facilities were tested through this process.

In addition to the call store facility queueing tests, a test of the performance of the system during a message store overload was made. Load control procedures were initiated which allowed current inputs to continue until they were complete, but restricted the acceptance of any further input traffic until the output process could make storage space available.

3.3.5 *Call Store Tests*

Capacity of a store and forward system is generally defined in terms of the system's thruput capability, that is, the number of characters transmitted and received by the switching machine per unit of time. In line-switched electronic switching systems, capacity is primarily limited by the real-time capability of the central processor. However, in store and forward systems, the requirements for storage are much greater. The system is committed to accepting originating traffic without regard to whether the traffic can be delivered to the terminators. Large amounts of storage are required to hold or queue the traffic for delivery to the terminators in addition to the storage required for the bookkeeping associated with transmission to and from the switching machine. In the No. 1 ESS ADF system, the call store capacity, as well as the real time of the central processor, limit the system capacity under certain traffic characteristics. Storage space is assigned by two basic considerations: that which is associated with transmission—the greater the storage, the higher the thruput that can be obtained—and that which is associated with holding traffic in the system—the greater the storage, the longer the traffic may be held in the system—which, in turn, means that transmission facilities can be used more efficiently. Both of these functions are vying for the same pool of finite storage.

The current call store allocation for the New York system was based on a traffic survey made by the Long Lines Traffic Department. The recommended assignment of call store for all traffic-dependent areas based on this design load is shown in Table II. The five major items—input processing registers, output processing register, assembly-disassembly blocks, message processing blocks, and message queue registers—require 88 percent of the assignable area with message processing blocks requiring more storage than all other items. For this reason, the major traffic engineering effort was placed on these five items in the development of assignment rules.

To test the adequacy of the call store assignments, several load box

TABLE II—PRESENT CALL STORE ASSIGNMENT FOR TRAFFIC DEPENDENT FACILITIES

Facility	Words per Register	Number Assigned	Total Number of Words	Percent
Assembly disassembly blocks	32	544	17,408	16.2
Input processing registers	16	150	2,400	2.2
Output processing registers	19	331	6,289	5.8
Message processing blocks	32	1645	52,640	48.7
Message queue registers	3	5500	16,500	15.2
Other items			2,724	2.5
Unassigned area			10,038	9.4
Total			107,999	100

runs were made varying the traffic intensity of the presented load. During these runs, the quarter-hour traffic printouts provided by the ADF system were used for capacity measurements and for average usage of each call store facility. Peak values for the call store usage counts were obtained by reading the traffic counters inside the ADF system about once per minute.

The peak and average usage of each facility as a function of traffic load was analyzed. As a result, the present procedures for engineering call store appear to be quite valid, with some minor changes. Making use of these changes in the traffic engineering procedures, Fig. 15 illustrates an approximate relationship between the number of call store words required per input line and the average input load per line. The number of call store words include the requirements for input transmission (input processing registers, assembly-dissassembly blocks, and message processing blocks), output transmission (output processing registers, assembly-disassembly blocks, and message processing blocks), and holding traffic on the message queue (message queue registers). This illustrates the design choice between call store facilities for input and output transmission and facilities for delaying traffic. As the input load increases, a breaking point is reached where the load on each output line is one erlang. At this point there is a choice of adding more output lines and associated call store output transmission facilities or adding only message queue registers to hold the traffic for future delivery. The latter is less expensive if one can put up with the increased service delays.

Some knowledge of the future traffic requirements is needed to make recommendations concerning future traffic engineering and call store assignment of the ADF system. Call store must be put to the most effective use to reduce transmission plant cost while meeting the traffic needs. The maximum number of call stores were provided with the New York system. It is, therefore, assumed that the network load will increase as a result of the addition of stations to the present plant in preference to the addition of large quantities of transmission facilities. In the process, the load on individual lines should be balanced.

Because future traffic requirements are unknown, Table III proposes an allocation of call store in which a traffic load of about 3.5 times the present Long Lines load can be handled. If the Long Lines traffic forecast indicates that capacity levels are needed beyond that which can be achieved with the call store allocation of Table II, additional transmission plant cost will be incurred. By converting all the 100 words per minute lines to 150 words per minute, the amount of data

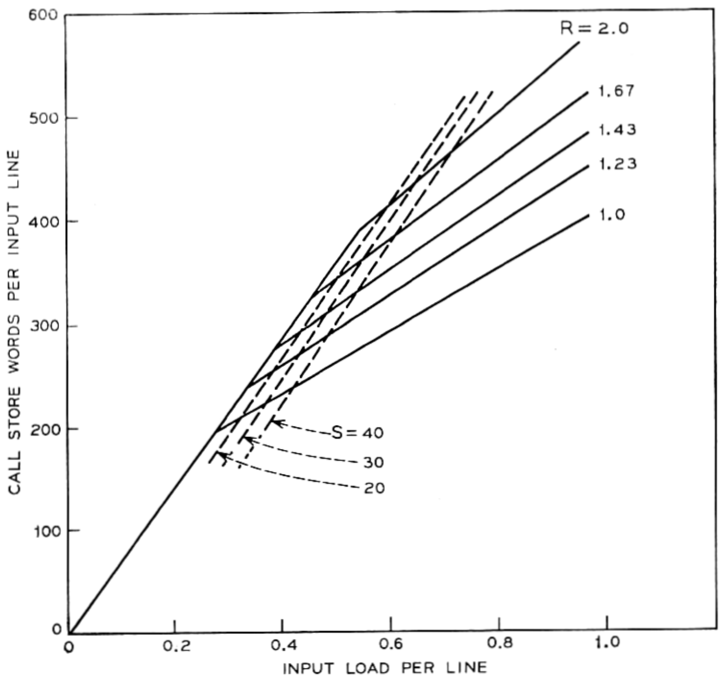

Fig. 15—Approximate call store requirements per input line as a function of load per input line for the major traffic dependent registers. S = Service delay in minutes. R = Ratio of output to input lines. Output message length: 1200 characters. "Busy hour": 1 hour followed by a low traffic period for emptying message queues. Multiple address factor: 3.0.

TABLE III—PROPOSED CALL STORE ALLOCATION FOR TRAFFIC DEPENDENT FACILITIES

Facilities	Words per Register	Number Assigned	Total Words	Percent
Assembly-disassembly blocks	32	711	22,752	21.1
Input processing registers	16	182	2,912	2.7
Output processing registers	19	415	7,885	7.3
Message processing blocks	32	1,333	42,656	39.5
Message queue registers	3	10,006	30,018	27.8
Other items			1,776	1.6
			107,999	100

passing through the computer would approach the system's real-time capacity, and a traffic load of about five times the present Long Lines load could be handled. The system capacity limits are summarized in Fig. 16.

IV. FIELD EXPERIENCE

By May of 1970, the No. 1 ESS ADF switching system at 811 Tenth Avenue, New York, had been in continuous operation for 15 months. During that time, hardware and software changes were introduced to

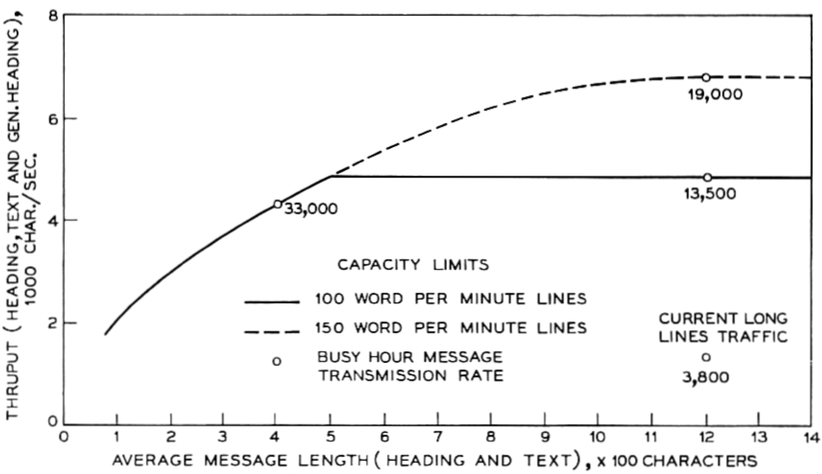

Fig. 16—No. 1 ESS ADF capacity limits: —— 100 wpm lines; - - - 150 wpm lines; ○ busy hour message transmission rate.

correct troubles encountered, new service features were added, and a final generic program was installed without interrupting service.

Although certain operational difficulties were encountered during the early months, the system has performed satisfactorily. The network is now being used to handle all Long Lines administrative messages, commercial service orders, traffic service orders, service results, payroll, plant circuit orders and expense analysis reports. As shown in Fig. 17, over 20,000 messages (originated plus terminated) were handled daily in the first month of operation. As new projects were added to the network, the daily traffic grew to 35,000 messages averaging 1,200 characters each. Additional traffic will be added during the next year to increase the load to 120,000 messages daily.

4.1 *Service Experience*

4.1.1 *Grade of Service*

The quality of service of a store-and-forward system may be measured by the: (*i*) delivery time of messages, (*ii*) number of lost or misdirected messages, and (*iii*) number of station troubles per day. Because of the nature of store-and-forward service, no one criterion tells the whole story.

The pick up and delivery time of messages depends on how heavily a multistation line is loaded and, therefore, is a function of engineering rather than switching center service. On lightly loaded lines, the

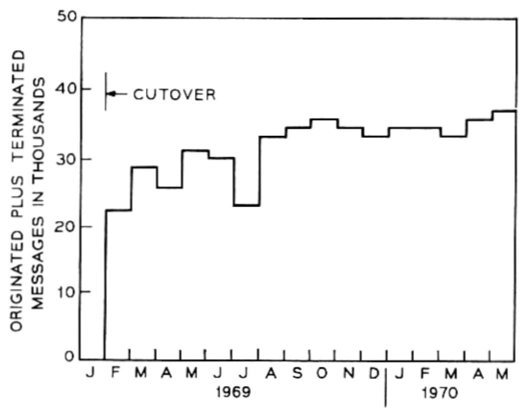

Fig. 17—Administrative-data network average daily traffic, with an average message length of 1200 characters.

pick up is immediate and the delivery to any station on the administrative-data network is less than one minute. On heavily loaded lines, pick up delays may be as long as 20 minutes and delivery may be delayed varying amounts depending on the length of the queue for the terminating station. Customer reaction to service has been excellent, but some additional lines have been added in some locations to reduce overload on key message center lines.

During the first week of operation, some messages were lost during a duplex disk failure. Since that time over 10,000,000 messsages have been handled without loss or misdirection of messages accepted by the system. About one message in 5,000 is undeliverable and the originator is asked to send the message again.

The number of station and transmission troubles is about one-fifth the monthly Bell System average for conventional teletypewriters in the field. This improved performance can be attributed to the teletypewriter electronic controller, new data sets, and continuous monitoring of the network by the No. 1 ESS ADF switching center.

4.1.2 *Message Retrieval*

The number of retrieval requests have been averaging about 250 per day or about 0.7 percent of daily traffic. These retrievals are needed by the user because of station problems, loss by local attendant, delivery to an additional terminator, or desire for a second copy. The breakdown for each of the above categories is not known in detail, but most retrievals result from station problems. The amount of retrieval traffic is below the level predicted and the retrieval service given has proven satisfactory to the user.

4.1.3 *Network Management*

The network management center described in Ref. 3 has proven to be very effective in managing a network as large as the Administrative-Data Network. On many occasions when traffic bottlenecks occurred because of transmission or terminal outages, network management personnel were able to pinpoint these bottlenecks and reroute the traffic until the line or station troubles were cleared. In addition to the specific network management features, the memory capacity of the system also is helpful in handling large backlogs of traffic. For example, the system provides for an interconnection with off-line commercial computers which process payroll data and other projects. Because these commercial computers are occasionally out of order, messages destined for the data processing center cannot be delivered and traffic in excess of 1,000 messages has been stored and queued for delivery in No. 1 ESS ADF for a day or more.

4.1.4 *Network Maintenance*

The normal maintenance procedure for data transmission and station plant is to test and repair facilities in the light of customer trouble tickets. To identify trouble before a customer reports it, No. 1 ESS ADF has been designed to locate trouble within seconds and report the trouble automatically to the maintenance center. This is possible because the switching system is programmed to poll every station not originating or terminating traffic every two seconds. By analyzing the results of polling and other "handshaking" signals, it is possible to determine station problems such as power failure, teletypewriter out of paper, jammed paper, or general station failure. Open, shorted, or noisy lines are also detected and reported to the maintenance center.

These automatic trouble reports now supplement customer trouble reports and, in many cases, malfunctions are being fixed before the customer is aware of a problem. The average time to repair administrative-data network data line and station troubles is below the Bell System average for similar equipment.

4.1.5 *Addition of New Features*

As a result of early operational experience, several new features seemed desirable to improve system performance. For example, improvements were made to identify the specific error in a heading format of a rejected message so that the originator could more easily make corrections. Provisions were also made for automatic control of a tape punch or other auxiliary equipment at a station by using address mnemonics. Features also were added to improve the procedure for introducing translation changes for new lines and stations.

The new or improved features were introduced temporarily without service interruption and were all included in the final generic program.

4.2 *Operational Problems*

4.2.1 *System Down Time*

The No. 1 ESS ADF switching center and the network it controls are designed for continuous operation without loss of messages or delays in message delivery. As described in Refs. 3 and 4, the programs were designed so that auditing programs could monitor and correct any call store words which were mutilated by software or hardware malfunctions. In addition, special programs called "emergency action programs" were provided to take care of excessively mutilated data which could not be handled by audits, or failures of system operation which could not be cleared by simple maintenance. These programs restart certain registers and memory locations and make it possible for the system to recover and continue processing.

Such emergency action programs are divided into four successive phases, each automatically called in if the situation is not corrected by the preceding one. The first three are relatively short and do not interfere with data processing. Phase 4 lasts about 40 seconds and does interrupt processing. However, this does not significantly affect service since originations are queued for input and output and the delay is not noticeable to the customer. Messages already accepted by the system are not mutilated, but messages being originated while a phase 4 program is in progress are aborted and the originator is automatically advised to send the message again.

These defensive tactics proved to be very effective in reducing system down time during the early months after cutover as they were able to maintain satisfactory service even with hardware and software troubles. Figure 18 shows the system down time since cutover. The relatively high down time shown during February and March resulted from program and hardware troubles not detected until after

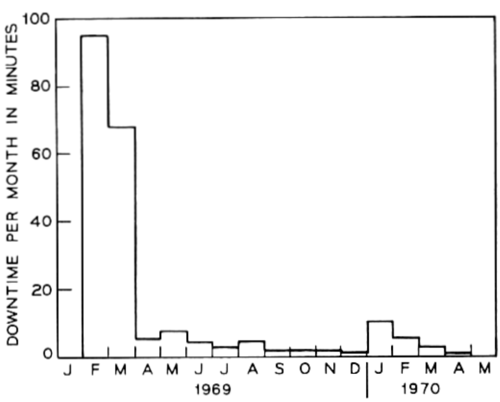

Fig. 18—System downtime in minutes.

a continuous live load had been placed on the system. These troubles were rapidly corrected. Total down time per month then dropped dramatically and has varied from 1 to 5 minutes per month. During January 1970, when the final generic program was introduced, several phase 4 emergency programs were required before the system would run satisfactorily on the new generic program. These emergencies accumulated 10 minutes of down time during the midnight hours.

4.2.2 *Types of System Problems*

Analysis of trouble reports show that software accounted for many of the early troubles. Program troubles were encountered in the tape retrieval system when it was under heavy retrieval load. Unfortunately, the load test facilities used before cutover were not capable of testing a heavy message retrieval load. Several other problems not sensitive to load, but to improper system operation by the user became evident. For example, one user tried to send a 905-multiple address message. The design limit is 379 addresses, with a check to reject messages asking for a greater number. However, the program was in error and did not detect the illegal request, so the machine switched automatically to emergency action programs.

Some maintenance programs were too sensitive. For example, thresholds for allowable error rates were set too low and, in some cases, the maintenance strategy of system reaction to malfunction had to be revised.

After the initial software troubles were corrected, the remaining troubles generally resulted from either hardware failures or improper procedures by maintenance personnel. Circuit pack failures were few and in line with previous data, as reported in Refs. 5 and 6.

Two analog units in the system, the tape transport and the disk file, required the most attention. The tape transport is sensitive to dirt, tape wear, and transport adjustments. Since 12 tape units are available, the problems were not critical to system operation, but they did require considerable maintenance. New alignment procedures, cleaner rooms, and close inspection of magnetic tape quality has reduced the troubles.

The disk file had failures in head diodes. An improved diode is now available, which is gradually being put into service. The disk file also had several "head crashes;" that is, the head touched the rotating disk, scratching off the magnetic coating. Such head-touching problems can most likely be attributed to dirt. New routines have been set up for cleaning the sealed disk units periodically and replacing the 0.2 micron dirt filter more frequently. The long term solution appears to be the development of a closed self-purging system so that air is recirculated and dirt is not allowed to accumulate.

V. CONCLUSION

The development of No. 1 ESS ADF has resulted in the design of several new types of hardware and the creation of some new testing techniques. The introduction of this system puts into Bell System operation for the first time disk files, acoustic delay lines, magnetic tape retrieval systems, and an electronic autonomous scanner-distributor for data lines. Newly introduced are: batch program debugging on an ESS machine, dual position program test console with matchers that can be set electronically, program controlled computer load testing, real-time printout of monitor dump facilities, and a complete set of improved utility programs to facilitate program compiling, loading, debugging, and insertion of program changes.

The operation of the new system at 811 Tenth Avenue, New York, since cutover, has been very satisfactory. Although the system is not being loaded to handle maximum traffic now, a live load test was run to demonstrate very large traffic handling capability and the ability to operate in real-time overload without mutilating, aborting, or losing messages. The measured traffic handling capacity of this system is a function of message length. For example, the system can handle 19,000 messages per hour for 1,200 character messages or 33,000 messages per hour for 400 character messages.

The system has proven to be reliable and during the last 15 months has handled 10,000,000 messages without loss. The monthly system down time is averaging about two minutes per month with excellent prospects for further reduction as more experience is gained with the system.

The field experience gained since cutover confirms the effectiveness of the service features, the adequacy of system traffic capacity and the reliability of system operation.

VI. ACKNOWLEDGMENTS

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