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# *No. 4 ESS:*

# System Integration and Early Office Experience

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*This article describes the special equipment and test procedures developed for system-testing the No. 4 ESS toll system. It discusses novel methods developed for the coordination of hardware and software changes and testing in various system laboratory configurations. Planning, engineering, installation, and testing of early offices are described. Early field experience with the first operational No. 4 ESS is presented. This office, a selective routing tandem located in Chicago, went into service on January 17, 1976.*

## I. INTRODUCTION

A No. 4 Electronic Switching System was installed in Chicago to provide toll service between metropolitan Chicago and selected area codes in the United States. The new system was cut into service on January 17, 1976. During a three-month period, 150 local Chicago switching offices were connected through the new Chicago toll office to 57 toll offices in California, Illinois, Florida, and Ohio. This cutover was the culmination of seven years of designing, manufacturing, and testing the new No. 4 ESS toll switching system. A second No. 4 ESS office in Kansas City, Missouri, was cut into service on July 3, 1976. Two more offices, Jacksonville, Florida, and Dallas, Texas, went into service in December 1976, and nine more offices are scheduled for service in 1977.

The development and testing of a toll system of this complexity was a sizable undertaking. The framework for integrating such a system was laid down in the initial planning stages of the project, and was supported throughout by the existence of design standards, documentation requirements, and control procedures. Some of the important aspects, in this regard, in the No. 4 ESS development were:

(*i*) Design standards for both hardware and software were developed and documented early in the project, and almost without exception, followed throughout.

(*ii*) A procedure for the overall design of the system, as well as for each hardware and software unit, was specified. The requirements for No. 4 ESS are based upon the requirements for a Bell System toll office. For each unit developed, two levels of design specifications were written, reviewed, and approved. The top level was known as a requirements design specification, and the second level as an implementation design specification. Each approved document became the vehicle for the next development step.

(*iii*) Procedures for documenting both hardware and software changes were developed very early in the project. These documents provided the vehicle for the institution of control and coordination procedures as required.

(*iv*) The development of test facilities was begun at the same time as the development of the system and was subjected to the same standards and development procedure requirements.

(*v*) Early in the development, it was decided that there would be no field trial and that the development would progress directly from a laboratory test to the first commercial installation. By January 1970, Chicago had been identified as the site of the first installation and a first office planning committee had been formed.

The following sections of this article describe how the overall laboratory and field testing was implemented. The excellent performance of the overall system at cutover resulted not only from good design but from the thorough planning, scheduling, and testing of the system before cutover.

## II. TESTING THE SYSTEM

The testing and design verification of No. 4 ESS was accomplished in three distinct phases. In the first phase, the many units making up the system were tested individually. The definition of a "unit" was rather broad. For example, hardware unit testing included verification that individual circuit packs met their design requirements and also that all of the frame types used in No. 4 ESS worked together in a laboratory environment. Software unit testing encompassed everything from simulating small software modules to verification that, for example, the data administration system correctly handled all specified input messages.

The second phase of the job was called functional testing. In this phase, the objective was to verify that not only was each system function cor-

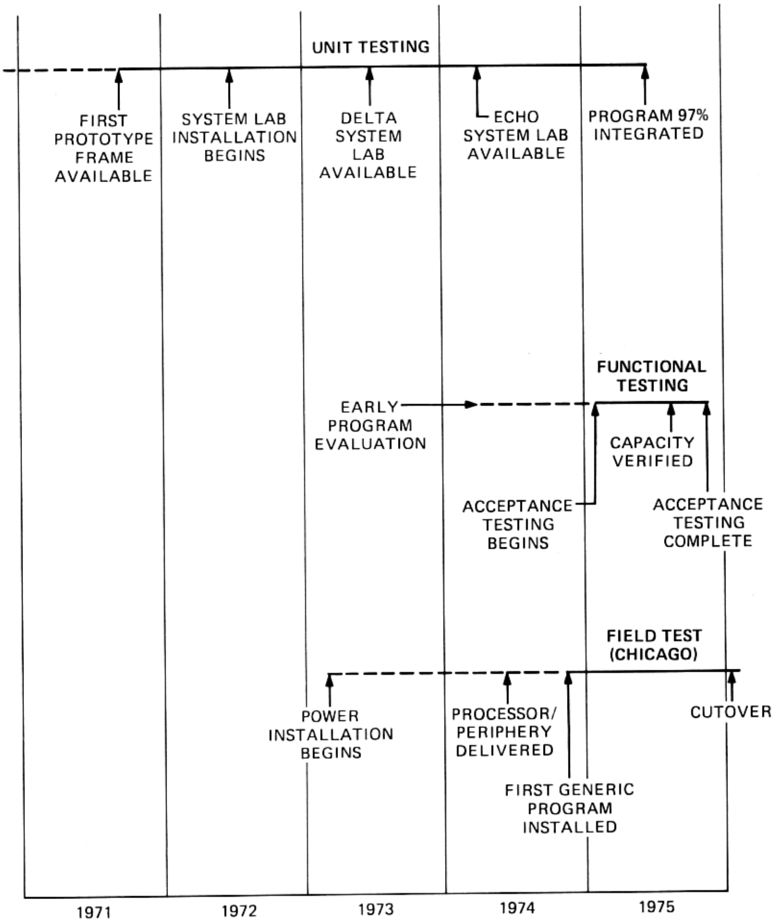


Fig. 1—Testing of No. 4 ESS.

rectly performed, but that the system remained stable during the performance of any combination of instructions.

The third phase was the evaluation and testing of the No. 4 ESS system under field conditions. In this phase, unit and functional tests similar to those run in the laboratory were repeated in order to provide a baseline from which to test the system in its operating environment.

The testing of No. 4 ESS was a continuing effort for a period of five years, as shown on Fig. 1. While the objectives of each testing phase were distinct, the phases overlapped in time. This overlap was accomplished by beginning functional testing as soon as unit tests on a cohesive set of features were completed, and beginning field testing as soon as usable stability was achieved. Also shown on Fig. 1 are several major benchmarks referred to in the next sections.

## III. UNIT TESTING

### *3.1 Hardware—early testing*

Initial verification of the hardware design was done using a logic simulator called LAMP,[1,2] running on a general-purpose computer. The LAMP simulator was capable of handling units varying in size from circuit packs of several hundred gates to frames of several thousand gates. In addition to verifying the hardware design, the test sequences used to detect and locate faults in the circuits were verified using LAMP.

Once designed and LAMP-tested, circuit pack models were constructed in Bell Laboratories' model shops and tested by the designers. Some skeletonized frames were constructed at Bell Labs to verify concepts and check timing. However, the general reliance was on Western Electric for production of prototype equipment. The first of a kind for each frame was built by Western Electric and tested by the designers at Bell Labs using a minicomputer-controlled test set. Since the Bell Labs and Western Electric test sets were compatible, once the test data base was designed and verified at Bell Labs it could be transferred to Western Electric and all future frames tested in the factory. Exactly the same test data forms the basis for the Installation Test System described in Section 5.2 and the generic diagnostic program.[3] As individual frame types were verified, groups of prototype frames were brought together in hardware laboratories where frame intercommunication and further operational checks were made.

### *3.2 Software—early testing*

Just as the early hardware testing was done with a simulator (LAMP), early software was first verified on an ESS program simulator running on a general-purpose computer. While all software could not be completely tested on the simulator, it proved to be a very efficient way of eliminating a large percentage of bugs early in the development. In all, 90 percent of the generic code was tested on the simulator. As was mentioned previously, most of the diagnostic tests (also approximately 90 percent) were verified in frame test and in the Installation Test System.

Before an operational 1A Processor was available, further testing of the software was accomplished using an available No. 1 ESS Processor. To do this, the No. 1 ESS Processor was slightly modified and connected via a No. 4 ESS peripheral unit bus branching frame to a signal processor, time-slot interchange, and time-multiplexed switch. The program, written in a combination of 1A Processor assembly language and ESS Programming Language (EPL), was translated so as to run on the No. 1 ESS Processor. Sufficient progress was made in checkout of the operating system and call-handling programs to allow a call to be completed

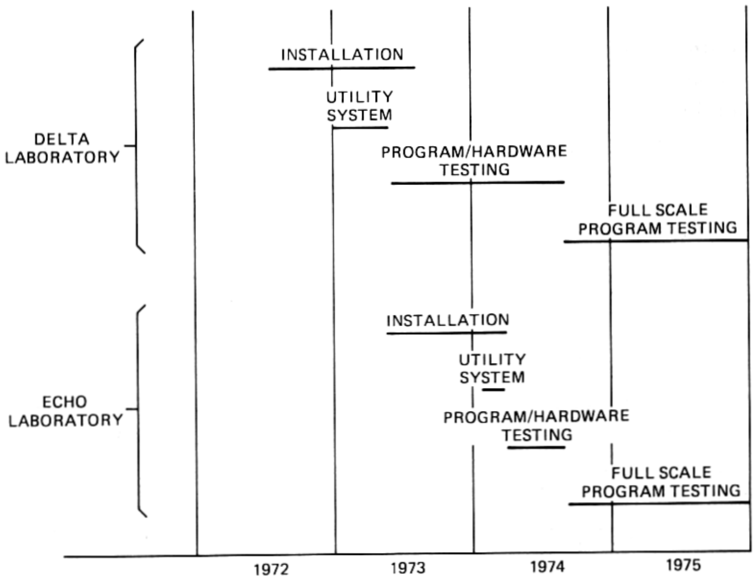


Fig. 2—No. 4 ESS system laboratory activity.

on November 2, 1972, seven months before a 1A Processor was available for general-program debugging.

### *3.3 System laboratories*

Two system laboratories were devoted to testing No. 4 ESS. A system laboratory consists of a 1A Processor, a minimum set of No. 4 ESS peripheral hardware, and transmission switching interface and toll terminal equipment. An additional system laboratory containing only a 1A Processor was also used, mainly for testing 1A Processor common programs.[4,5] There were two reasons for having two complete system laboratories. First, the initial laboratory, which we called Delta, contained prototype equipment, while the second laboratory, which we called Echo, was made up of production equipment. Having Echo guaranteed that testing, especially the testing of changes, was carried out in a realistic environment. The second reason for two system laboratories was to double the available program testing time in order to meet the cutover schedule.

As shown on Fig. 2, activity in each system laboratory began with installation and testing of the equipment and utility system.[6] Program checkout began on June 1, 1973, in Delta and on April 1, 1974, in Echo. However, in both system laboratories, the initial program debugging began in an environment of continuing hardware debugging and hardware change activity. Many of the hardware changes, involving both wiring and circuit pack change, came about as a result of problems found when operating with the generic program. One measure of change activity is shown in Fig. 3. The curve shows the cumulative number of wires changed in the two system laboratories during 1974 and 1975. Change activity consumed a great deal of laboratory time in early 1974, but began to level off by August when basic operating stability was achieved. It then increased slightly and continued at a relatively uniform rate throughout most of 1975. However, in this later period the changes generally were such that they did not cause extensive interference with program debugging. The approximately 40,000 backplane wires changed in the system laboratories in 1974 and 1975 were about 1.5 percent of the total number in the laboratories.

Beginning August 1, 1974, both system laboratories were devoted to full-scale program checkout. Full-scale program checkout was defined to be the point where 16 hours a day were scheduled for program debugging and where at least 80 percent of the scheduled time was actually productive. Unproductive time was caused by such things as hardware failures or change activities not being completed on schedule.

From the time program debugging began, the system laboratories were operated in two different modes. One was a closed shop, batch-type mode where programmers submitted test decks, which were run by operators, and printouts returned. Of the total system laboratory time available

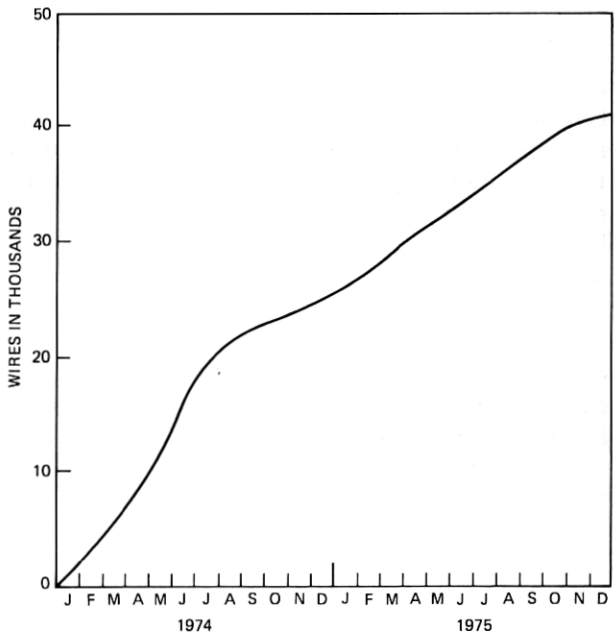


Fig. 3—Cumulative backplane wiring changes in Delta and Echo laboratories.

for program debugging during the unit testing interval, approximately 55 percent was devoted to batch operation. The availability of a powerful utility system and automated testing aids[6] made this mode of operation viable.

The remaining system laboratory program debugging time was devoted to hands-on operation. Hands-on time was assigned when required by specific problems, such as those whose solution required the interplay of a programmer with debugging tools and a hardware designer with oscilloscope, and also where problems existed which were impeding future debugging progress in other areas. In this second situation, a small group of programmers was assigned blocks of time. Much of the time was used running "instant turn-around" batch-type test jobs for these programmers.

Using both batch and hands-on techniques, a program debugging rate of about 20,000 instructions a month was sustained from September 1973 through February 1975. The fast startup of program debugging, shown in Fig. 4, was a result of the extensive pretesting of both the hardware and software.

## IV. FUNCTIONAL TESTING

### *4.1 Laboratory system testing*

An independent system test group was chartered to provide a systemic testing viewpoint. A set of system-level test sequences was generated

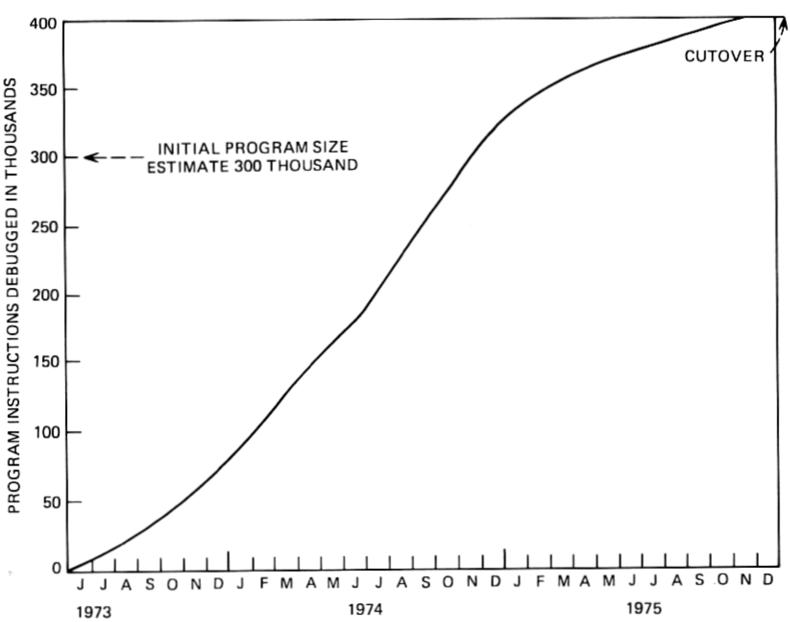


Fig. 4—No. 4 ESS program integration.

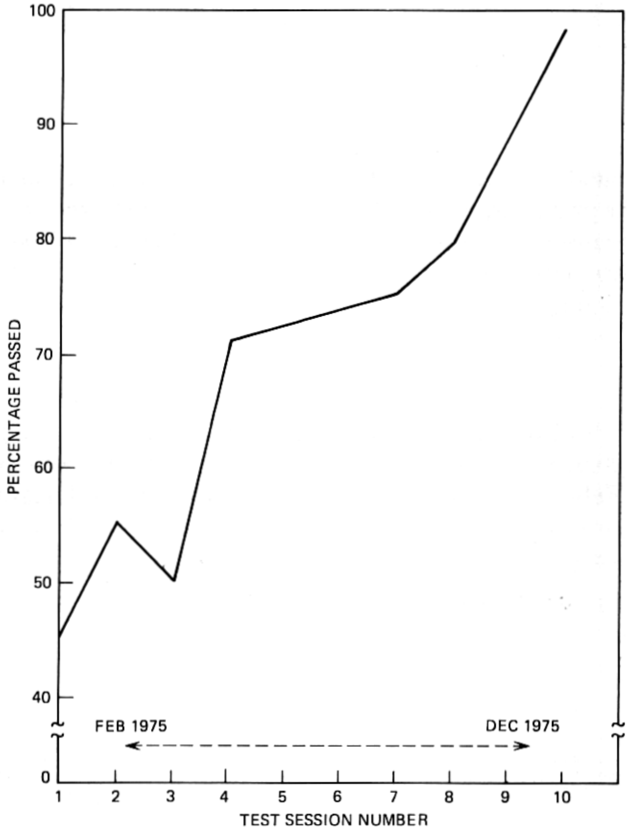


Fig. 5—Laboratory acceptance testing.

and executed in a controlled, highly interactive environment. A subset of these test sequences was used as a generic system laboratory acceptance test. This acceptance test was executed periodically during the functional testing interval, and the statistical performance results, as a function of time, were used to indicate the rate of achieving system stability. The results of the acceptance tests are presented in Figs. 5 and 6. Figure 5 shows the percentage of tests in an acceptance test that executed as expected. Figure 6 shows the mean time between unscheduled major recovery events. Both are graphed as functions of time. Absolute numbers were not used as prime indicators, rather the slopes were used and, as can be seen, both figures indicate that system stability was being achieved.

The highest-priority goal of the functional testing interval was to achieve system stability in the presence of system faults. This was focused on with the firm conviction that this characteristic was funda-

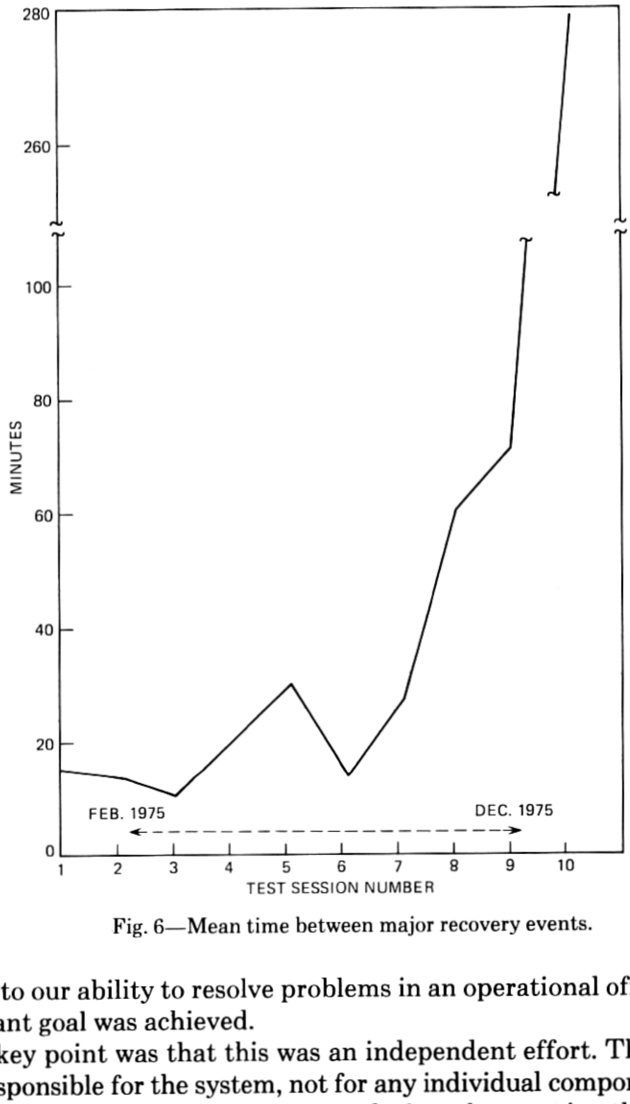


Fig. 6—Mean time between major recovery events.

mental to our ability to resolve problems in an operational office. This important goal was achieved.

The key point was that this was an independent effort. The people were responsible for the system, not for any individual component of it. They ensured that the system was ready for release, using the system laboratory as the testing vehicle. This was achieved by the system test group being the focal point of change control and also the primary interface with the field test group.

### *4.2 Laboratory System Evaluation*

A great deal of effort was spent to ensure that No. 4 ESS would meet all of its real-time objectives. Early in the project's life, numerous real-time simulations were developed and executed to establish confidence that these objectives would be met. These simulators were designed such that after the system laboratories became operational, the same experiments could be run there to verify the simulator results. These experiments were done in three areas: (*i*) system response versus call attempts per hour; (*ii*) system overload control responses as a function of call load; (*iii*) system engineering requirements versus real-time capacity. In all three cases, the simulator results were verified, and in the case of real-time capacity, allowed us to increase the advertised capacity from 350,000 to 550,000 engineered call attempts an hour.

In summary, we were able to verify our simulated system performance characteristics, and thus, to achieve all engineering requirement system objectives.

## V. ENGINEERING AND PLANNING EARLY OFFICES

### *5.1 Selection of Early Offices*

There were many locations at which there was need for a large toll switching machine. Chicago was chosen jointly by AT&T, Bell Labs, and Illinois Bell as the site for the first No. 4 ESS for a number of reasons. It is conveniently close to both Bell Labs at Indian Hill, the development location, and to Western Electric at Lisle, the principal manufacturing location. This proximity facilitated support during the installation, testing, and initial service periods. In addition, the office, called Chicago 7, was planned to be a new-start office rather than a replacement. This avoided many problems that would have been associated with the cutover of in-service facilities from one office to another. It permitted the development of a simple phased cutover and contingency plan.

Kansas City was chosen as the site of the second office, called Kansas City 2, in part, in order to face the problems associated with replacing an in-service 4A crossbar office with a No. 4 ESS. These problems include the reuse of existing toll terminal equipment and the development of flash cutover procedures.

The selection of subsequent offices was done by Long Lines and AT&T and was based on need for additional switching capacity and the buildup in Western Electric production rate.

For both Chicago 7 and Kansas City 2, office planning committees were organized with representatives from AT&T Headquarters, Long Lines Headquarters, local Long Lines Operations and Engineering, Western Electric Product Engineering Control Center and Installation, and Bell Labs. These committees were distinct from and in addition to the normal operating company cutover committees. The planning committees established schedules for office engineering, manufacturing, installation, and testing. Progress was reviewed regularly and problems were solved as they arose. Because many decisions were required before standard methods had been developed and documented, Bell Labs engineers did much of the engineering of the processor and network for Chicago 7. Western Electric's Product Engineering Control Center participated in this effort and developed the standard engineering questionnaire as a result. The transmission facilities for Chicago 7 were all new and posed no special problems. They were engineered by Long Lines and installed by Western Electric. Because Kansas City 2 was to be a replacement for an existing 4A crossbar office, the reuse of an existing set of transmission facilities raised many questions about methods of connection to No. 4 ESS, trunk circuit compatibility, and segregation of private line and switched circuits that were mixed in existing carrier systems. The economics of reusing existing older equipment compared with replacement by new toll terminal equipment was also considered. Bell Labs System Engineering worked closely with operating company engineers to answer these questions.

As part of the system development, standard floor plans were developed for the major elements of the system, i.e., 1A Processor, time-division network, signal processor–voiceband interface cores, and toll terminal equipment. Therefore, the preparation of floor plans for Chicago 7 and Kansas City 2 was simplified to arranging these large blocks, rather than individual frames, in the available space.

### 5.2 Installation Test System

Concurrent with the development of the No. 4 ESS, Western Electric engineers developed factory frame tests and installation tests based on the common tests described earlier. A key element in the design of No. 4 ESS is that a single set of tests be developed and used for all testing of a particular type of unit, i.e., single unit testing in the factory, system testing during installation, and diagnostic testing in an in-service office. Installation Test System (ITS) is the name of the program used by the Western Electric installation testers to control the execution of unit and subsystem tests. ITS is characterized by permitting tests to be run simultaneously on several different pieces of equipment. A prerequisite for the beginning of system testing at Chicago 7 was that all ITS unit and subsystem tests pass successfully. The testing activity at Chicago 7 spanned a period of 1½ years starting in mid-1974 when ITS tests were begun. Figure 7 shows the sequence of tests through the phased cutover in early 1976.

### 5.3 Field Test Plan

A field test plan consisting of functional tests, environmental tests, and an overall acceptance test was written and used as a final check that the system met its functional objectives at specified environmental

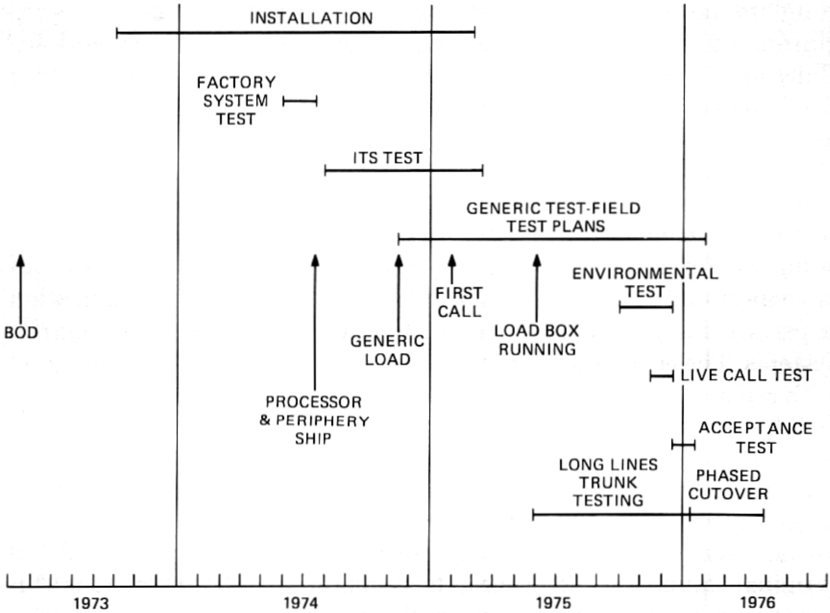


Fig. 7—Chicago 7 testing activity.

limits. About eleven thousand individual functional tests were written and most were executed several times during the system test interval at Chicago 7. The environmental tests verified system performance at the limits of high temperature and low voltage. A program-generated call load of 80,000 calls per hour was applied in order to verify the adequacy of the office engineering. In addition, six persons at real telephones placed several thousand calls in order to get a subjective measure of the system performance. Final acceptance of the system as ready for commercial service was based on tests during which the system was operated for several days by the Long Lines craft while it was switching test traffic.

This functional testing interval began on one shift a day in November 1974, increased to two shifts a day in January 1975, and went to three shifts a day in March of 1975. During this period, many tasks competed for system time. In addition to the execution of field test plans, time was required for the installation of hardware design changes, program corrections, ordinary maintenance troubleshooting, and testing and alignment of the connecting trunks by Long Lines. Although several tasks might be executed at the same time, careful scheduling was required to avoid the many incompatible combinations of system use. From the earliest stages of planning the system integration and testing, it was agreed that there would be no scheduled program debugging at Chicago

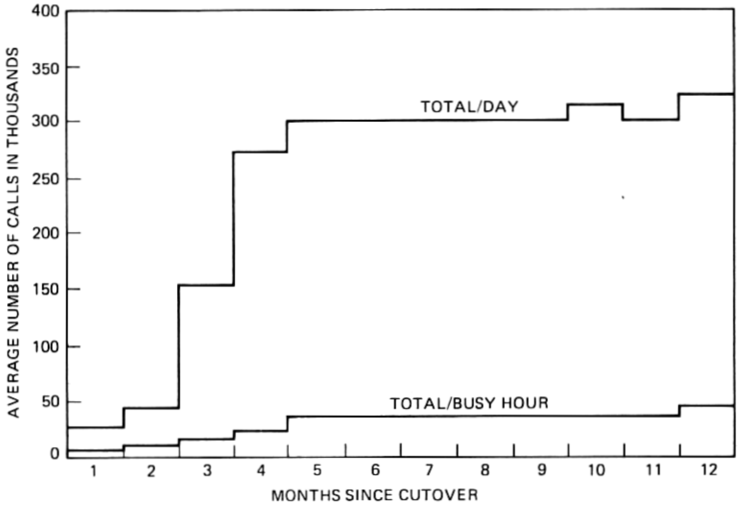


Fig. 8—Chicago 7 traffic.

7 in order to avoid yet another demand for system time. Despite thorough verification in the system laboratories, there were occasions when program tests were run at Chicago 7 to identify problems that were unique to the office because of its size, hardware configuration or data base. Despite these occasional lapses, the normal procedure was for system performance problems to flow from the field test group to the system test group and for integrated programs and tested changes to flow to Chicago 7.

## VI. CHICAGO 7 PERFORMANCE EVALUATION

The cutover of Chicago 7 was accomplished on the schedule set in 1972. The cutover was of the phased type, covering the period January 17 to April 24, 1976, during which about 4500 toll connecting trunks from 150 local offices in the 312 NPA and a nearly equal number of intertoll trunks to 57 toll offices in foreign NPAs were put in service. Traffic data for Chicago 7 are shown in Fig. 8. Traffic built up as trunks were added and reached a busy-day high of 350,000 and a busy-hour of 31,000 calls at the completion of the phased cutover. Additional trunks to the NPAs originally served were added in the summer of 1976 and trunks to New York City were added starting in the fourth quarter of 1976. The trunking configuration for Chicago 7 at the start of 1977 is shown in Fig. 9.

There are several criteria for judging the performance of an electronic switching system. These include the number of ineffective attempts, as a measure of the grade of service received by the customer, and measures of the required maintenance effort on the part of the operating company.

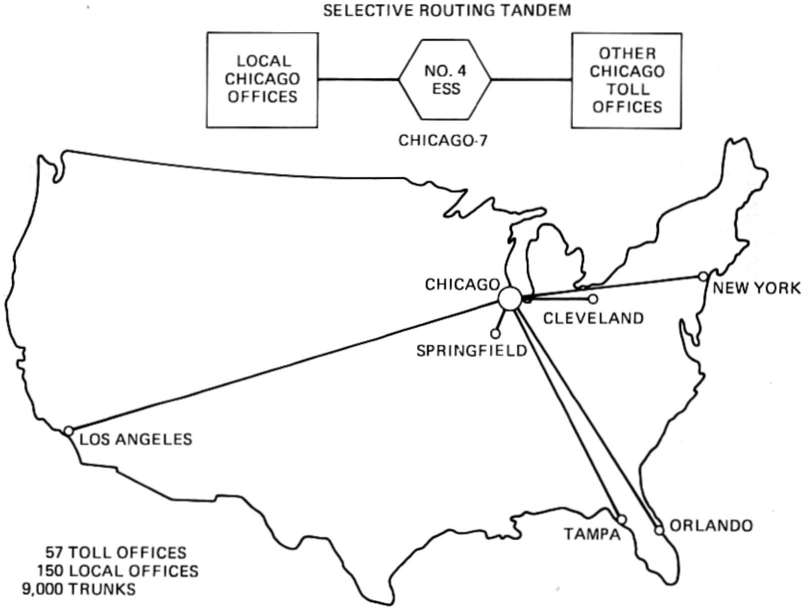


Fig. 9—Chicago 7 trunking.

Prior to cutover, two criteria were set for each of a number of measurements, Table I. These were a desirable objective and second a level at which the advisability of putting the office into service would be questioned.

Ineffective attempts result from sources external to the switching machine as well as from internal causes. Figure 10 shows the history of ineffective attempts at Chicago 7 for the first year of service. The most recent data show total ineffective attempts averaging less than 1 percent.

The replacement rate for plug-in apparatus is one measure of the maintenance effort required. Figure 11 shows the monthly average of the daily replacement rate through the first year of service. During the first 122 days of service, there were 413 plug-ins of all kinds replaced,

Table I — Cutover performance criteria

| | Objective | Concern threshold |
|---|---|---|
| Ineffective attempts | 1.25% | 3.0% |
| Plug-in replacements | <2/day | 7/day |
| Interrupts | <50/day | 200/day |
| Phases (2 or higher) | ½ month | ½ day |

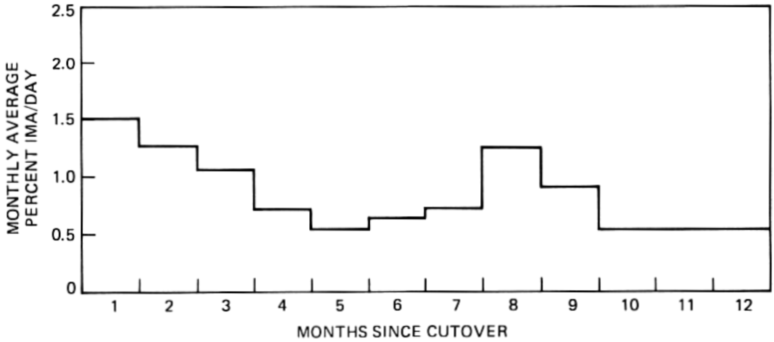


Fig. 10—Chicago 7 ineffective machine attempts.

for an average replacement rate of 3.4 a day. The present average replacement rate is between 2.5 and 3.0 a day.

A maintenance interrupt occurs whenever the system experiences an event of sufficient importance to interrupt the normal flow of program control in order to take immediate action. Maintenance interrupt actions require only a few milliseconds and have no impact on customer service. They are, however, a measure of required maintenance activity. Another measure of system performance is the number of occurrences for which the system response was a memory reinitialization phase[3] of sufficient severity to have an impact on call processing. Neither a phase 2 nor a phase 3, either of which can be run automatically, will disturb calls in the talking state, but these phases will prevent the completion of calls in the process of being established. A phase 4, the most severe reinitialization, can be induced only by manual action. A phase 4, in addition to preventing completion of transient calls, will disconnect stable calls in the talking state. One observation is that there is a tendency for one

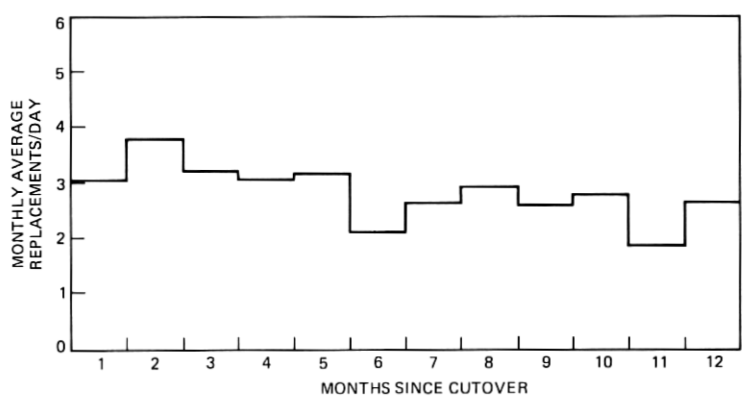


Fig. 11—Chicago 7 plug-in replacements.

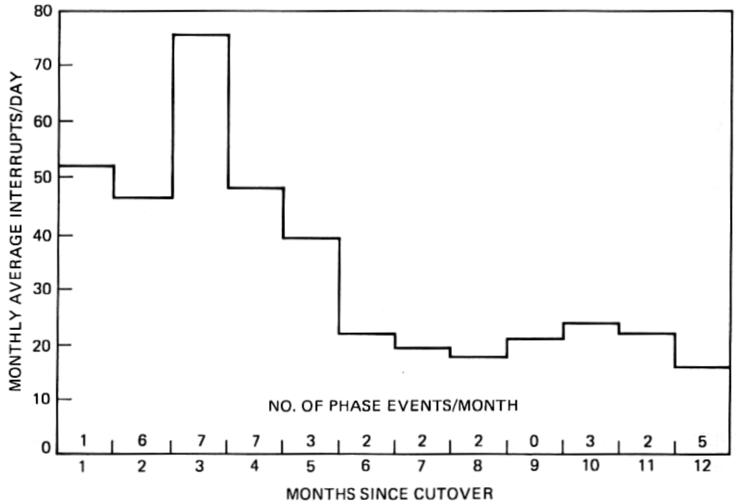


Fig. 12—Chicago 7 interrupts and phase events.

stimulus, e.g., a hardware failure, to trigger a number of phases in rapid succession. Each such incident has been studied in detail and these studies have resulted in a number of improvements in the maintenance program strategy. Transient hardware errors resulting from marginal equipment failures are one of the most difficult classes of problem for the system to cope with. Figure 12 shows both the monthly average of the number of interrupts a day and the occurrences of maintenance incidents that required one or more reinitialization phases.

## VII. SUMMARY

The successful introduction of No. 4 ESS into commercial service in Chicago 7 resulted not only from good design but also from a large effort directed toward system testing and integration. Initiated early in the development process, these efforts included careful planning for measuring system performance and coordination of the introduction of hardware and program changes. This ensured that the process converged toward a stable and satisfactory system design.

The overall performance of the Chicago 7 system has been excellent. No fundamental system problems have been encountered, although some software and hardware improvements have been incorporated as a result of operational experience. It is expected that all performance objectives will be reached in the near future as a result of additional craft training and recently introduced system improvements.

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