INTRODUCTION

Since LLL's computer complex, or network, is in operation 24 hours a day, 7 days a week, maintenance procedures and controls have been or are in the process of being developed which minimize disruption of user service. The challenge of developing such tools and procedures is intensified by the diversity of hardware within LLL's system—CDC, IBM, DEC, Ampex, Lockheed, General Precision,* and LLL—and by the number and type of users on-site—1,000-plus scientific and administrative users. Although designed for a time-sharing system (designated at LLL as the Octopus), many of the tools and procedures apply to a stand-alone system as well since the integrity of each user (host) computer to function as an independent entity has been preserved. Tools and procedures described include on-line and off-line diagnostic software. In addition, fail-soft procedures (recovery procedures effecting minimal system interruption) developed at LLL are described. In conclusion, the diagnostic tools and procedures are evaluated and findings from samplings of system availability are presented.

This paper presents not a theoretical approach to the problem of computer system maintainability, but rather the evolutionary techniques extant at Lawrence Livermore Laboratory.

OVERVIEW OF LLL’S COMPUTER NETWORK AND ADMINISTRATIVE POLICIES

Description of network hardware

LLL’s computer network presently has five user, or host, computers; namely, three CDC 7600’s (Serial Nos. 1, 2, and 17), a CDC STAR-100 (Serial No. 1), and a CDC 6600 (Serial No. 13). A letter identification (R, S, T, A, and L) has been used to designate each machine (Figure I).

The CDC 6600 has a 128K-word memory, ten PPU’s (peripheral processing units), three disks with approximately 1.3 billion bits, eight tape drives, a card reader, a printer, a punch, and a DD80 35mm microfilm recorder and display scope.

Each CDC 7600 has a 64K SCM (Small-Core Memory), 512K LCM (Large-Core Memory), ten PPU’s, two disks with approximately 10-billion bits, a 160-million bit drum, eight tape drives, a card reader, and a printer.

The CDC STAR-100 has a 512K-word core memory, five input/output (I/O) stations, two paging drums (approximately three times core memory), two disks (7600 equivalent), four 9-track tape drives, a card reader, and an on-line printer.

The control, or hub, computer consists of two DEC PDP-10 processors and their shared 256K-word memory (Figure 2). It is directly connected to the host computers by high-speed (12 MHz) interfaces to transport data between the host computers and the shared data base which consists of a trillion-bit IBM Photostore, a 3.2 billion-bit IBM data cell, and eight 707-million-bit CDC 844 disk packs. The hub computer also has dedicated a 880-million-bit General Precision Librascope disk which is used as an intermediate storage and buffering device. A PDP-10 processor also controls the TMDS (Television Monitor Display System) which via a 16-channel, 128-position switch connects 128 television monitors, each of which can have additional monitors serially attached. A color capability also has been implemented.

Four DEC PDP-8’s serve as concentrators and control the Teletype (TTY) sub-network. Each PDP-8 may have 128 interactive teletype terminals attached and may be connected to two host computers. A PDP-8

* Work performed under the auspices of the U.S. Atomic Energy Commission.

* Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Atomic Energy Commission to the exclusion of others that may be suitable.
PDP-10
- Evans and Southerland Graphics complex

PDP-10 File Transport and Storage Network
- IBM Data Cell
- IBM Photostore
- General Precision Disk
- CDC 844 Disk Pack
- Television Monitor Display System

0 Series PDP-8 Teletype Network
- 40 Teletypes expandable to 128

200 Series PDP-8 Teletype Network
- 128 Teletypes

400 Series PDP-8 Teletype Network
- 128 Teletypes

600 Series PDP-8 Teletype Network
- 128 Teletypes

PDP-11/20 Based Remote Job Entry Terminal Network
- 12 card readers/line printers expandable to tapes, cassettes

PDP-11/45 Based Graphics Terminal Network
- 40 terminals expandable to 128

PDP-11/45 Based (Developmental) Graphics Terminal Network
- 8 terminals expandable to 128

PDP-11/20 ID Computer
- Dynamically assignable data-channel connections.

Figure 1—Octopus distributed network

Two Princeton Electronics graphic terminal sub-networks are used for remote visual graphical interactivity. They have a 256-expanded-character-set capability. An additional sub-network of RJET's (Remote Job Entry Terminals) provide for I/O at remote locations of the Laboratory. At present, each terminal consists of a
TTY, 600-lpm printer, and 400-cpm card reader; however, they can be expanded to include magnetic tape and tape cassettes.

A user mode within the hub computer system allows the use of one PDP-10 processor to drive the Evans and Sutherland, LDS-1 computer and its associated interactive graphics terminals.

Administrative policies and procedures

User access accountability

All network accesses, whether it be day or night, individual user or computer operator, are via TTY remote terminals. An identification message must be transmitted which identifies the host computer being addressed, the user, the user's division, and, if required, security level accessibility. Additional operator and division user numbers are required during production periods under operator control. (Job mix, priority, interactivity, and maintenance procedures are controllable by the operator.)

The executive systems—designated STAR on the CDC STAR-100, FROST on the CDC 6600's, FLOE on the CDC 7600's, and HYDRA on the PDP-10—verify the ID messages and establish appropriate linkage. In addition, the executive systems verify time allocation by machine per day, night, and weekend; authorized users within each divisional account; and the percentage level each user may draw upon its division's total time allocation for each period.

LLL's executive systems are written and maintained in-house. While it may seem that much effort is spent "inventing the wheel," at least that wheel precisely fits the vehicle for which it is intended. The time delays normally associated with adding new system features or fixing old ones are minimal, and the constraint of compatibility with the rest of the world does not exist other than at compiler and assembler levels. The ability to tailor-make an executive system architecture has facilitated the implementation of LLL's maintenance and fail-soft procedures.

Dissemination of network performance to users

All TMDS terminals, when otherwise not in use, display a dynamic system status which is continually updated by automatic system messages and by operator-initiated information messages. Automatically, the PDP-10 (hub computer) periodically pulses each of the components attached to it and displays their status on the TMDS monitors. For instance, if a user is running direct from a TTY to a host computer via a live and healthy PDP-8 and if the interface connecting that PDP-8 to the PDP-10 is not functioning, that linkage would be reported as failing. Each "Operator Information" (OP INFO) message initiated by the operator or automatically by the system is placed in a buffer and sent to all TTY's, in addition to being displayed on the TMDS. TTY messages forewarning the user of system interruption, tape backlog, and system dead starts, for example, are helpful in reducing user frustration (sometimes).

Another communication medium used is the "Octogram," a daily news release which keeps the user up-to-date on day-by-day activity. The "Octopus, Communiqué" is a more detailed and permanent documentation medium sent to all computer users. These communiques describe system modifications, additional sub-routine or utility routine functions and other information of a permanent form prior to its release in a formal document or manual.

Bi-weekly C.I.E. (Computer Information Exchange) meetings enable further communication. On alternate weeks, Computation staff members meet with repre-
sentatives from LLL's major computer user divisions and departments to discuss methods which, hopefully, will result in procedures that will satisfy their needs.

Fault analysis and liaison

First level investigation and determination of computer malfunctions is undertaken by the Systems Operations Section (SOS) of LLL's Computation Department. This section acts as a focal point and collection agency of facts and determines appropriate remedial action. SOS assists the operating staff, system programmers and the various engineering maintenance personnel (IBM—Data Cell/Photostore; CDC—Host Computer; LLL—Hub Complex) on an on-call, 24 hours-a-day basis.

In addition, an operator on each shift is appointed to keep in close touch with the Systems Operations Section, and each engineering group responsible to the time-sharing system also has an appointed liaison. Consequently, explicit formal channels exist for rapid communication.

MAINTENANCE TOOLS AND TECHNIQUES USED

Host computer diagnostic software

On-line software automatically scheduled

A subset of manufacturer's standard diagnostic software for the CDC 6600 and CDC 7600 is used to check functional units, memories, arithmetic precision, and random operand performance. Since these routines are automatically scheduled by the executive system and run as part of the normal operational job mix, they are subject to all the operating system idiosyncrasies of scheduling, loading, and timing and provide in a real-time sense a meaningful measure of hardware status.

The CDC 6600 routines run every 30 min for 20 sec each. The CDC 7600 routines run every 15 min for 1 sec each. Errors cause the offended routine to be restarted at twice its current time limit. The restart process has been programmed to continue until the error is no longer noted (error designated as intermittent) or machine is extensively diagnostically pre-empted (solid). Errors noted are sent to the operator's output TTY station, and pertinent memory dumps are hardecopied for the customer engineer. If the diagnostic failures are intermittent, maintenance decisions become a value judgment; that is, if the frequency of the error is low, immediate maintenance action may be deferred.

On-line remote execution software

On demand or desire, diagnostic software may be executed from remote stations without noticeably perturbing the operational job mix. This remote execution may be initiated by any user; however, it is usually done only by systems or maintenance personnel. An extensive open-ended job set is available which has been designed to exercise the mainframe and central processing unit (CPU) as well as peripheral hardware.

Off-line diagnostic software

Maintenance actions may require the suspension of all user services. If the suspension can be scheduled and does not involve write destruction of disk or memory system tables, the operational job mix can be saved to disk and automatically restarted after the maintenance action is complete. Manufacturer's standard diagnostic software is available.

Hub computer diagnostic software

On-line software automatically scheduled

The following diagnostic tests are automatically scheduled and executed by the executive system:

(1) Every 30 sec, 1 page of random data (512 36-bit words) is written to the G-P Librascope disk, read back, and compared. The disk controller hardware VERIFY function is also checked, and pertinent error comments are output to the operator's console TTY station.

(2) Every fifth data burst (maximum 64K 60-bit words) out of the hub computer to any device is read back and compared. Pertinent error comments are output to the operator's console TTY station.

(3) Every 30 sec the status ("hung" or "responding") of the IBM Data Cell is sampled. Pertinent error comments are output to the operator's console TTY station.

(4) Every time the IBM Photostore is referenced, its status ("up and available," "disconnected," "in recovery," etc.) is recorded on the TMDS, and pertinent error comments are output to the operator's console TTY station.

(5) Each time the TMDS display is updated (3.5 sec), the hub computer sends a message to each host computer and to each PDP-8. If there is no reply, this fact is noted by the hub computer. If
the device fails to reply three times in a row, the status is recorded on the TMDS as follows: “DOWN” for the nonresponding PDP-8 and “N/R” for the nonresponding host; date and time of status report are also included.

(6) Every error detected by the hub computer when reading or writing on the G-P disk, Data Cell, and Photostore is trapped and analyzed. A 15-line message, which includes the device, time of error, type of error, status of all control registers, and number of retries, is output to the engineer’s TTY station. These printouts become a permanent log of all I/O errors detected by the hub computer. Persistent errors (catastrophes) invoke an automatic recovery procedure involving the hub computer executive system reload. Error comments are made, and three bells are sent to all TTY stations signalling the event. Every attempt is made to insure the integrity and automatic completion of the hub’s job queue.

On-line remote execution software

Diagnostic routines designed to evaluate network components may be executed from a remote station by systems or maintenance personnel. These routines are time-shared in the hub computer.

(1) Specialized tests include:

- Photostore controller tests
- disk pack tests
- data acquisition system tests

Each tests the specified devices under simulated operation conditions since the device itself must be off-line. The routines send control messages, set or read status registers, and check data transmission using any of the various sub-channels available.

(2) Inter-machine tests

A complex of six routines is used to exercise and evaluate all possible communication paths within the file transport network. These routines determine the status of control functions, communication links, clocks, and interfaces between the hub computer and the designated host or remote terminal. (Interfaces include multiplexors, selectors, adapters, file channels, and line units.) When required for the test, a PDP-8 and a host PPU or remote terminal are dedicated to the diagnostic tests and unavailable to the operational network.

Off-line diagnostic software

In a stand-alone mode, an additional series of diagnostic programs exist which include operational tests for:

- console TTY
- tape reader/punch
- CPU instructions
- priority interrupt hardware
- data transfers
- memory protection and relocation
- processor timing
- I/O bus
- internal clock
- G-P disk—saturation
- memories—LLL, Ampex, Lockheed
- Data Cell

These tests are of two classes: (1) those which send control messages and verify responses, and (2) those which test data transmission paths by sending patterned data, having the device echo the data back via hardware control, and then comparing with the original data. All these tests can run in either a single-step or continuous mode.

Fail-soft procedures

Fail-soft procedures are considered to be those recovery processes which allow a resource flexibility and rapid automatic error recovery.

Commands enabling resource flexibility and sharing

Circumstances arise when it is desirable to have within the system an easy method of managing hardware resources. In developing this fail-soft capability, a comprehensive set of commands has evolved. Commands available include:

P ALL HSP Send all printer output to tape for off-line processing on the high-speed printer. The printer can now go down for maintenance.

D N MMM N is a disk unit number 1 through 4. MMM is either “In” or “Out.” This will allow or prevent, respectively, the...
creation of new files on disk N. If “Out” existing files remain accessible and disk N can be scheduled down for maintenance.

SP NNNNNN IN TEXT

Allows only privileged user number NNNNNN access to the host. All users’ programs are saved on disk, and all attached TTY stations are logged out. The TEXT is sent to all users attempting to log in to the host.

For a complete list of commands refer to the Appendix.

These commands are initiated from the operator’s input console TTY station and communicate with the executive system or with any active user’s remote TTY. The commands provide a necessary resource flexibility in that no hardware device is permanently dedicated. Within the framework of these commands, the operator can provide back-up capabilities for I/O devices such as drums, on-line printers, and on-line punch. He may also elect to restrict the creation of all disk files to a specified disk unit or to prevent the usage of specific disks and/or tape units.

This management of tapes, disks, drum, printers, and other resources is desirable not only for back-up purposes, but also to make maintenance activities easier. The operator may take any specified device off-line for maintenance without disturbing the job queue or interrupting service to the active users. These devices may also be returned to service without interruption to the active user. In addition to the ability to manage peripheral hardware resources, there are commands that terminate the time-sharing process and restrict use of the system. This capability is particularly convenient when a suspect hardware failure develops that requires the host system to be dedicated to the task of error detection or machine maintenance. When this requirement exists, the operator disconnects all codes that are active in memory and requeues them on disk. The integrity of these codes is assured since there is an option within the command set to re-initialize the job queue. Similar techniques to manipulate devices attached to the hub computer are available to a privileged set of users.

Additional hardware flexibility is achieved by resource sharing: File transport channels can be used as secondary back-up routes for transmitting Teletype message packets when a PDP-8-to-host machine link is lost. Card readers and tape transports may also be shared by more than one host computer.

Dead Starts

The philosophy of dead starts has always been to minimize the consequences resulting from the dead start. The dead start options which have evolved represent LLL’s progress in realizing that goal. Although circumstances requiring manual intervention and the consequent dead start vary, every effort is made to use the option inflicting the least hardship on the user. At the “softest” level, all disk files are preserved and disk queue jobs eligible for loading are automatically restarted. Unless the SP NNNNNN IN command was used before the machine failed, all jobs residing in memory are disconnected and removed from the operational job queue. At the “hardest” level all files are lost; all jobs are disconnected; and a recent tape copy of the public (permanent) files is restored to disk.

The dead start commands which follow are initiated from the engineer’s console keyboard/display scope:

- **DS** Preserves all disk files and the disk queue. All in-memory jobs are disconnected.
- **DSD** Identical to DS plus a pertinent memory dump is hard copied for the system’s programmers.
- **DSR** Preserves all private files and the disk job queue. All in-memory jobs are disconnected. Public files are restored.
- **DSU** Preserves most disk files; all jobs are disconnected. The disk file catalog (index) tables are restored from drum. Since the file index to drum save is a periodic function (2 min) some temporary (private) disk files may be lost.
- **DSN** Preserves public files. All private files are lost, and all jobs are disconnected.
- **DSB** All public and private files are lost, and all jobs are disconnected. Public files are restored.
- For the preceding dead start options, all executive system reloads are initiated from the drum.
- **DSC** Transfers the executive system from tape to drum; a DSC must be followed by the appropriate dead start option.

Automatic recovery for memory parity errors

An automatic recovery procedure for intermittent memory parity errors has been implemented within LLL’s 7600 executive system (FLOE). This fail-soft technique requires no operator intervention, maximizes user availability, and allows for the prescheduling of
memory maintenance actions. In the case of a memory error in a user code area, only that code is affected. All other jobs proceed normally and without interruption. The affected code is disconnected and removed from the operational job mix. Errors occurring in executive system memory areas require a reload (dead start) from drum of the affected system coding or tables. This procedure requires less than 1 min. The integrity of the operational job mix is subject to the particular dead start option, DS or DSU, instituted. The automatic recovery procedure does allow for a deferment of maintenance actions to a time period less visible to the user. This ability to schedule emergency maintenance periods has maximized system availability during prime usage periods.

Fault possibilities and dead start options are as follows:

<table>
<thead>
<tr>
<th>Memory Error In</th>
<th>Option Instituted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resident executive system coding</td>
<td>DS</td>
</tr>
<tr>
<td>Resident executive system tables</td>
<td>DSU</td>
</tr>
<tr>
<td>Resident user program</td>
<td>None*</td>
</tr>
</tbody>
</table>

The operating system determines the intermittency of the memory parity error by four-patterned reads and writes of the affected memory area(s). If the error does not reappear, automatic recovery is initiated and normal time-sharing resumes. A pertinent diagnostic comment describing the error is output to the customer engineer's TTY station and the operator's console TTY station. An entry is made in the event-file, and a fatal error status is returned to the offended user's program if the error occurred within a user's program.

It is a standard operating procedure to require emergency maintenance (EM) if the same recoverable parity error occurs twice within 2 hr. The SP NNNNNNN IN command would be used to allow for the automatic restart of the operational job mix at the completion of the maintenance action.

**Dynamic disk flaw tables**

Before a CDC 7600 disk file is declared available for general use, a static table of flaws is generated. These flaws represent areas of the disk that contain hard faults (solid read parity). These data are incorporated into the appropriate operating system tables during a DSN or DSB dead start option and remain a permanent part of the systems flaw table data base. Flawed areas, one disk sector (512 60-bit words) in length, are not available for assignment to a program requesting disk space.

During normal time-sharing periods, the system flaw table data base is dynamically maintained. After thirty-two consecutive disk read failures, an entry is made in the file catalog index of the offended disk file, and an appropriate error status is returned to the program. No further system action is taken, and the disposition of the offended file is entirely under the control of the executing user program. When the program releases (destroys) the offended file, executive system action is required to ascertain the solidity of the flaw.

If the executive system cannot perform an error-free read of the disk sector containing the flaw, the flaw table data base is dynamically expanded. A diagnostic comment detailing the error is output to the operator's console display scope and the event-file. The dynamic flaw table entries are maintained over all dead starts not requiring the loss of private files (see dead start section).

Ideally, no static flaw tables need to be maintained; however, user frustration levels have been dramatically reduced by not requiring the continued re-discovery of known hard flaws. The transference of flaw entries from the dynamic to the static table is done periodically when it is determined an area of disk has indeed developed a hard fault.

**Magnetic tape integrity**

Insuring the integrity of magnetic tapes and associated tape transport hardware continues to be a major maintenance problem. User frustration levels reach all time highs when recorded information cannot be reliably retrieved. Since tapes seem destined to be with us for a considerable period of time, a major effort has been made to alleviate the problem.

All manufacturers suggested hardware modifications have been made. Vendor maintenance has been increased. All physical tapes are certified before release. All operators are educated in proper tape handling procedures. Tape transport heads and vacuum columns are cleaned periodically (once per hr).

Assuming perfect tapes and functional hardware, tape integrity is now assured. In a real world sense, however, extensive write recovery software procedures had to be implemented. The primary assumption is that if a tape can be written with no error indication, it can be read error free. Therefore, during the write operation, only bad parity records must be verified as having been rewritten correctly, i.e., the rewritten record and associated record gap and erased area must be error-free readable.

* The faulted user program is disconnected.
Utilizing this recovery has reduced our non-recoverable error rate to less than 0.01 percent from as high as 10 percent.

An extensive remote time-shared tape testing program is also available on the host computers. This test allows the simultaneous evaluation of tape transport hardware, software drivers, and physical tapes in the real-time environment.

Stand alone ability

The integrity of each host computer to function as an independent entity has been preserved. In the advent of a failure in the PDP-8/PDP-10 Teletype network, the ability to communicate with a host would be completely removed. While that portion of the host's operation job mix requiring no Teletype interaction would continue to run, no new jobs could be entered in the system.

To prevent the host from becoming "idle," a Teletype Simulator (TTYSIM) version of the Livermore time-sharing system can be loaded. This system relies entirely on a console keyboard/display unit as the interactive input and output media. Other than the fact that system operation is now completely operator controlled, no restrictions or limitations are imposed on the operational job mix.

Current preventive maintenance policy

If it were feasible to have total hardware redundancy, on-line maintenance would not be required since all component repair time would be off-line, and hence invisible to the user. This, however, is not the case; therefore, maintenance policies and procedures must be established which attempt to insure minimum network degradation while maximizing total system availability.

Two diametrically opposed maintenance policies have been periodically tried and systematically discarded: (1) schedule large amounts of maintenance, and (2) schedule no maintenance.

Scheduling extensive maintenance periods did not work. Not only was the device or component off-line and unavailable for extended periods, but faults requiring an unacceptable number of unscheduled maintenance periods continued to occur.

Scheduling no maintenance periods only compounded the unscheduled maintenance problem and indeed resulted in significantly decreasing overall total system availability. By not allowing any scheduled or preventive maintenance periods marginal logic cannot be detected and replaced, nor can maintenance actions designed to increase total system reliability be performed.

The amount of PM time allowed is continually under review, and whenever the hardware shows an increased reliability, the PM periods are reduced.

Table 1 shows LLL's current preventive maintenance schedule and represents at best the current trade-off between the above maintenance philosophies.

Network availability during the prime usage periods

Figure 4—History of 7600 maintenance actions

Figure 5—Percent of total machine availability
TABLE I—Current Scheduled Maintenance

<table>
<thead>
<tr>
<th>Machine</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network hub</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>4:00-8:00</td>
</tr>
<tr>
<td>CDC 6600</td>
<td>a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4:00-8:00</td>
</tr>
<tr>
<td>CDC 7600</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td>b</td>
<td>4:30-8:00</td>
</tr>
<tr>
<td>CDC 7600</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td>b</td>
<td>4:30-8:00</td>
</tr>
<tr>
<td>CDC 7600</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>4:30-8:00</td>
</tr>
</tbody>
</table>

* CDC 6600 taken on alternate Mondays.

* Any two CDC 7600's may be taken, but not all three at the same time.

is maximized by conducting scheduled maintenance at a time least visible to the user (0400-0800 hours) and by selecting subsets of components to be down concurrently.

For comparison, the scheduled or preventive maintenance (PM) and unscheduled or emergency maintenance (EM) history for the CDC 7600 R (serial No. 1) and CDC 7600 S (serial No. 2) host computers is illustrated in Figure 4. These maintenance actions required the host computers to be off-line and therefore completely unavailable to the user. Figure 5 shows the average total percentage availability for the CDC 7600 R and S host computers, the CDC 6600 L (serial No. 13) and CDC 7600 M (serial No. 31) host computers and the total percentage availability for the PDP-10 hub or control computer. The percentages are arrived as follows:

\[
\text{Percent} = \frac{\text{Hours in Month}-(PM+EM)}{\text{Total System Availability}} \times 100
\]

\[
\text{Percent} = \frac{\text{Hours in Month}}{\text{Partial System Availability}} \times 100
\]

EVALUATION OF DIAGNOSTIC MAINTENANCE TOOLS AND PROCEDURES

The diagnostic maintenance tools do provide for rapid, positive identification and isolation when the component or device failure is solid. However, experience has indicated that most failures tend to be intermittent in nature and difficult to identify and isolate. Even though great amounts of time and money can be spent attempting to isolate intermittent failures, it has not been demonstrated at LLL that intermittent failures become significantly less intermittent when extensive off-line diagnostic periods are used. For this reason, it is concluded that it is better to catalog an intermittent error for administrative analysis, recover as softly as possible, and promptly return the device or component to full productivity rather than insist on the immediate off-line isolation of the problem.

Samplings (Figure 6) of system availability taken hourly Monday through Friday from 0800-1630 hours from November 1970 through April 1972 demonstrate the following:

<table>
<thead>
<tr>
<th></th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total System Availability (all devices on line)</td>
<td>75*</td>
</tr>
<tr>
<td>Partial System Availability (Useful work being accomplished by at least one host)</td>
<td>100*</td>
</tr>
</tbody>
</table>

ACKNOWLEDGMENTS

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REFERENCES

1 D L PEHRSON
   An engineering view of the LRL Octopus computer network
   Lawrence Livermore Laboratory Rept. UCID-51754 1970
2 Livermore time-sharing system manual M-026
   Lawrence Livermore Laboratory 1972
3 K H PRYOR et al
   Status of major hardware additions to Octopus
   Lawrence Livermore Laboratory Rept UCID-30036 1972

* Power failures affecting the entire network are not included in these figures.
APPENDIX

Commands available include:

**Printer/Punch**

- **P ALL P1** Send all printer output to on-line printer No. 1. Printer 2 can now go down for maintenance.
- **P ALL P2** Send all printer output to on-line printer No. 2. Printer 1 can now go down for maintenance.
- **P ALL HSP** Send all printer output to tape for off-line processing. Both on-line printers can now go down for maintenance.
- **P KILL P1** Aborts processing of current printer/punch files on indicated device.
  - or **P2 or PUNCH**
- **P2 HSP** Send all printer No. 2 output to tape for off-line processing. Printer 2 can now go down for maintenance.
- **P NORMAL** Restores operating status of printer output devices.

**Disk**

- **D N MMM** N is a disk unit number 1 through 4. MMM is either “IN” or “OUT.” This will allow or prevent, respectively, the creation of new files on disk N. If “OUT,” existing files remain accessible and disk N can be scheduled for maintenance.
- **DP N MMM** As described for the D option, but will also purge disk N of all existing files. All files on disk N are destroyed and are no longer accessible.

**Drum**

- **P DRUM DOWN** Transfers system tables from the drum to memory and rewrites these tables to a disk file. All subsequent attempts to access the drum will be redirected to the disk. This provides backup capability for the drum and allows the drum to be taken down for maintenance.
  - **P DRUM UP** Restores normal operating status of the drum. System tables that have been stored on disk during the drum down period are transferred from disk to memory and rewritten to the drum.

**Tape**

- **C N** Tape unit N is physically not available to the system.
- **F N** Tape unit N is physically available to the system.
- **E P** A tape error status is returned to program P.
- **X N** Severs logical connection between tape unit N and problem program.

**Execution**

- **SP** Allows only privileged user number NNNNNN access to the system. All users programs are saved on disk, and all users remote TTY stations are logged out. The TEXT is sent to all users attempting to log in.
- **SP** Removes privileged user number NNNNNN and automatically restarts previously running programs and restores normal time-sharing.
- **S TEXT** Prohibits any additional log in. TEXT is sent to remote TTY stations.
- **R** Restores normal time-sharing.

**Broadcasts**

- **I STORE TEXT** Sends the TEXT to all logged in remote TTY stations. Sends the TEXT once to all remote TTY's at log-in time. Sends TEXT to TMDS.
- **I ERASE TEXT** Erases the I STORE TEXT.
- **I BROAD TEXT** Broadcasts TEXT once to all remote TTY stations and sends TEXT to TMDS.