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SUBJECT: ANALYSIS OF RECENT PERFORMANCE RECORDS FOR THE WHIRLWIND COMPUTER SYSTEM

To: Distribution List

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Abstract: Comprehensive records of all system failures in the Whirlwind computer and its associated terminal equipment over a 20 week period show that the average uninterrupted operating time between failure incidents was 10.6 hours. The average time lost for each of the 244 incidents was 22.8 minutes. The percentage of operating time usable was 96.5 per cent. Computer alarms accounted for 37 per cent of the stoppages but only for 12 per cent of the lost time. Failures caused by design weaknesses required more time for correction on the average than the other classes of failure analyzed. Assuming that some major improvements in weak sections of the system had been carried out, it was estimated that the same failures might have averaged only 16.8 minutes of lost time per failure.

1.0 COMPUTER-PERFORMANCE RECORDS

1.1 Coverage

Following the revisions in the Cape Cod Direction Center facilities in July, 1954, the Whirlwind computer and its associated input and output system entered a period in which the equipment has remained relatively stable. In September, 1954, the procedures for gathering and evaluating performance data on the computer system were somewhat revised. This was done to permit more comprehensive analyses of system reliability with particular emphasis on interrupting failures. In general, the new procedures provide more complete data on all computer stoppages and a bi-weekly review and summary of these stoppages. The records are intended to reflect all failures in the computer and its terminal equipment that would have caused interruptions if the Cape Cod System had been in full scale operation continuously. Actually, for a large fraction of the time that the computer was in use, much of the Cape Cod terminal equipment was not required. (This terminal equipment comprises about 40 per cent of the entire system

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which has approximately 12,700 tubes). Under these circumstances, failures in the terminal equipment may not have resulted in loss of computer time. Failures which do not cause interruptions, however, must be considered in order to obtain an accurate picture of system performance. These are considered to be "potentially interrupting" and are given the same weight as those that actually halted operations.

1.2 Organization of Records

Past Whirlwind computer experience had indicated that most of the interrupting failures could be placed into a relatively few categories which defined either the cause of the failure or its principal symptom. In the record system set up last September, the following categories were selected:

Tubes	(cause)
Wiring, cabling, jacks, connectors, etc.	(cause)
Circuit components (other than tubes)	(cause)
Blown fuses	(symptom)
Computer alarms	(symptom)
Design weaknesses	(cause)
Miscellaneous	

The failures listed in the blown-fuse and computer-alarm categories are ones for which true causes cannot be immediately determined. In general, such failures have no associated equipment damage. Examples of incidents in the miscellaneous category are an insulation breakdown on a phenolic panel, an air conditioning failure, an unseated tube or loose wire inadvertently caused while doing essential maintenance, and a malfunction of a piece of terminal equipment which cleared up before the fault could be found.

For each failure, the amount of time lost is that time required to restore the system to operation after the interruption. In the majority of the component and circuit failures, this includes the time required to isolate and replace the defective item. In the newer sections of the system having plug-in units, it may include only the time to locate and replace the plug-in unit. For computer-alarm stoppages, it includes the time required to photograph the control and indicator panels and to record pertinent data on the program being run at that time. This information is then studied at leisure to detect possible causes of the alarms.

The records of interrupting and potentially-interrupting failures are further broken down to show those which must be charged against the system and those which can be attributed to new equipment installation or revision. Because the central computer and its terminal equipment are an integral electrical system, failures in new equipment can cause transients which interrupt the computer, even though the new equipment is logically independent of the rest of the system. Therefore, until a new installation has been debugged and adequate routine-maintenance procedures have been worked out, failures attributable to such equipment are not counted against the system.

2.0 ANALYSIS OF PERFORMANCE DATA

Several figures are needed to adequately describe the reliability of an electronic system. In general, system reliability is reflected in the amount of unscheduled down time caused by interrupting failures and in the amount of scheduled down time required for preventive maintenance. Since the amount of down time for different types of interrupting failures varies widely, the frequency of such failures is also an important factor in describing system reliability. In the following paragraphs such reliability figures for the Whirlwind computer and its associated Cape Cod terminal equipment are given. These figures were derived from an analysis of data gathered over the 20-week period from 28 September 1954 to 10 February 1955.

2.1 DERIVATION OF LOST-TIME AVERAGES

It was pointed out previously that sections of the Cape Cod terminal equipment are not involved in some of the computer applications work so failures in this equipment may not cause loss of computer time. Considering this varied use of the computer, two alternatives for obtaining representative figures of system reliability are suggested. Either (1) the analyses are restricted to the central computer alone, or (2) all failures (both interrupting and potentially interrupting) are counted and lost-time data is extrapolated to give a measure of over-all system reliability. The second method was chosen for the following reasons:

a. Accurate records had been kept of all potentially-interrupting failures that had been detected and the number of such failures was consistent with the number of actual lost-time incidents;

b. The central computer is not representative of some of the terminal equipment;

c. Since the terminal equipment is always on and can indirectly affect the central computer, isolation of failures to the central portion of the computer in some cases is questionable;

d. The records of time spent on preventive maintenance cannot be broken down among different sections of the system.

To determine the theoretical, or extrapolated, lost time for each category of failures, the average lost time per lost-time failure was calculated, and this average was multiplied by the total number of failure incidents (interrupting and potentially interrupting) in that category. The sum of the extrapolated figures for all categories is the total lost-time figure desired. This figure divided by the total number of failure incidents is the average lost time per incident for all incidents.

In determining the average lost time per failure for three of the categories, a few incidents were not considered in computing the averages because the time lost was disproportionately long. The failure-duration distribution for the three categories alarms, miscellaneous, and fuses is shown in Fig. 1. One incident in each of the first two categories and two incidents in the third were disregarded. A study of the records showed that three of these incidents had occurred during time assigned to the systems engineering group and that more time was spent in a thorough analysis of the failures than otherwise would have been required to restore operation. The fourth incident was a major air-conditioning failure which occurred on a week-end when service personnel were not readily available.

In Table I the number of lost time incidents and the amount of actual lost time for each category of failures are listed in the first two columns. The third and fourth columns show the number of incidents and corresponding lost-time figures used in computing the averages given in the last column.

TABLE I

LOST-TIME-FAILURE DATA

Category of failure	Number of lost-time incidents	Total minutes lost time	Data excluded in computing averages: Number of incidents	Data excluded in computing averages: Minutes lost	Average lost time per incident (Minutes)
Computer Tubes	15	447			29.8
Power Supply Tubes	7	412			59.0
Wiring, Cables, etc.	6	220			36.7
Components	8	349			43.6
Blown Fuses	15	346	2	160	14.3
Alarms	83	652	1	60	7.2
Design Weaknesses	15	1093			73.0
Miscellaneous	40	1626	1	750	22.5

Using the averages of Table I, extrapolated lost-time figures were calculated to reflect all failure incidents. These figures are shown in Table II. The totals in this table determine that the average time lost for the 244 failure incidents is 22.8 minutes.

TABLE II

EXTRAPOLATED LOST-TIME DATA

Category of failure	Number of no-lost-time incidents	Total number of failure incidents	Average lost time per incident (minutes) (FROM TABLE I)	Total extrapolated lost time (Minutes)
Computer Tubes	12	27	29.8	805
Power Supply Tubes	1	8	59.0	472
Wiring, Cables, etc.	1	7	36.7	257
Components	8	16	43.6	697
Blown Fuses	18	33	14.3	472
Alarms	8	91	7.2	655
Design Weaknesses	1	16	73.0	1168
Miscellaneous	6	46	22.5	1035
Totals		244		5561

$$\text{Average lost time per incident} = \frac{5561}{244} = 22.8 \text{ min.}$$

2.2 Analysis of Failure Categories

The extrapolated lost-time and average lost-time figures for the various categories of failures as given in Table II contain some interesting points. The failures in three categories, tubes (computer types and power-supply types combined), design weaknesses, and miscellaneous, were responsible for 63 per cent of the time lost, while 70 per cent of the failure incidents were in the alarm, miscellaneous, and blown-fuse categories.

The relative contributions of the various categories are better shown by the data in Table III. Each class of failures has three quantities listed, its percentage of the total failure incidents, its percentage of the total lost time, and the ratio of its average lost time per incident to the over-all average lost time per incident. Extremes in this data occur for the alarm and the design-weakness categories. Alarms were by far the most frequent type of failure while design weaknesses required the most time for correction. The computer records show that in several of the cases of design weakness, the marginal checking or other preventive maintenance facilities were inadequate so incipient trouble had not been detected and signal tracing techniques were required to locate the fault.

TABLE III

COMPARISON OF FAILURE CATEGORIES

Category of failure	Percent of total number of failure incidents	Percent of total lost time	Ratio of lost-time average for category to lost-time average for all incidents
Computer Tubes	11.0	14.5	1.3
Power Supply Tubes	3.3	8.5	2.6
Wiring, Cables, etc.	2.9	4.6	1.6
Components	6.6	12.5	1.9
Blown Fuses	13.5	8.5	0.6
Alarms	37.3	11.8	0.3
Design Weaknesses	6.6	21.0	3.2
Miscellaneous	18.8	18.6	1.0

Since tubes are known to have the highest failure rate of all components in a computer system, an estimate of the number of stoppages caused by tubes is of interest. For this estimate it is assumed that about 85 per cent of the alarms and blown fuses were caused by tube defects. With this assumption, then, approximately 60 per cent of the total incidents and 40 per cent of the time lost may be attributed to tube failures.

Some information on component-failure rates can be derived from historical records on the system. During the 20-week period in question, a total of 437 tubes were replaced in the system. Replacements for accidental damage were excluded. Since 35 of these were interrupting or potentially interrupting failures, about 92 per cent of the failures were located during scheduled maintenance periods. The tube-failure rate for all causes, computed from the data already given and from the total-operating-time figure listed in Section 2.3, is 1.49 per cent of the tube complement per 1000 hours. The rate for interrupting tube-failures is 0.12 per cent of the tube complement per 1000 hours. These tube-failure rates compare favorably with similar data which has been derived in the past by the group working on tube testing and evaluation.

The records on component replacement show that a total of 101 components other than tubes were replaced. Since there were 16 interrupting or potentially-interrupting failures caused by such components, about 84 per cent of the total failures were handled during scheduled maintenance time.

2.3 Over-All System Performance

By considering the total computer operating time and the amount of preventive maintenance and new installation work that was done, an over-all picture of system performance can be obtained. Significant figures are the following:

Total computer operating time	2675 hours
Total extrapolated lost time (calculated from averages)	92.7 hours
Average uninterrupted operating time between incidents	10.6 hours
Failure incidents per 24-hour day	2.19
Percentage operating time usable	96.5 per cent

The figure given above for percentage usable operating time as calculated from the extrapolated lost-time agrees closely with a figure of 96.2 per cent which is the actual percentage of "applications time" usable during the 20-week period as determined from operator reports. Applications time is the time during which the system is used by programming groups rather than by engineering and maintenance personnel.

A summary of the preventive maintenance and installation work is shown in the plots of Fig. 2. New installation and modification projects were essentially completed by the middle of the period. The required preventive maintenance also decreased and for about three months has remained relatively constant at about 1.25 hours per day.

A study of the failure frequencies over the 20-week period since September, 1954, does not show any meaningful variations. The total failure incidents as well as the number in each category are plotted for each two-week period in Fig. 3. Although the total number of failures dropped slightly during the last 8 weeks, the failure patterns for the various categories are too inconsistent to consider the decrease as a significant trend.

3.0 ESTIMATED PERFORMANCE OF IMPROVED SYSTEM

A review of the system-failure records points up the fact that a few sections of the computer have been responsible for an appreciable fraction of the lost time. If an engineering effort to improve these sections were justified, it seems reasonable that a significant reduction in lost time might be realized. In order to obtain some impression of what the system-performance record might be if this work were done, each incident was reviewed and lost-time figures were reduced for failures in those sections that might be improved. In making the estimates it was further assumed that all failures were repaired as rapidly as practicable as if they had occurred during applications time.

The data to be presented is not intended as proof that an improvement program should be undertaken on the Whirlwind system. Rather it it given to permit more realistic estimates of the reliability that might be expected in a new system design.

A summary of the estimated time lost under the conditions described above is given in Table IV. The largest reduction in time lost appears, as might be expected, in the design-weakness category, and some reduction is shown in all categories. If major system improvements had been accomplished, the number of failures in the design-weakness and miscellaneous categories could be expected to decrease. Since this would tend to balance any optimistic estimates for the other categories, the calculated average of 16.8 minutes lost-time per failure would seem to be reasonable.

TABLE IV

ESTIMATED LOST-TIME DATA FOR IMPROVED SYSTEM

Category of failure	Number of lost-time incidents	Estimated lost time (minutes)	Average estimated lost-time per incident	Total number of failure incidents (From Table II)	Extrapolated estimated lost time (Minutes)
Computer Tubes	15	292	19.5	27	527
Power Supply Tubes	7	262	37.5	8	300
Wiring, Cables, etc.	6	145	24.2	7	169
Components	8	239	29.9	16	478
Blown Fuses	15	149	9.9	33	327
Alarms	83	563	6.8	91	618
Design Weaknesses	15	623	41.6	16	667
Miscellaneous	40	865	21.6	46	993
Totals				244	4079

Average estimated lost time per incident =

$$\frac{4079}{244} = 16.8 \text{ min.}$$

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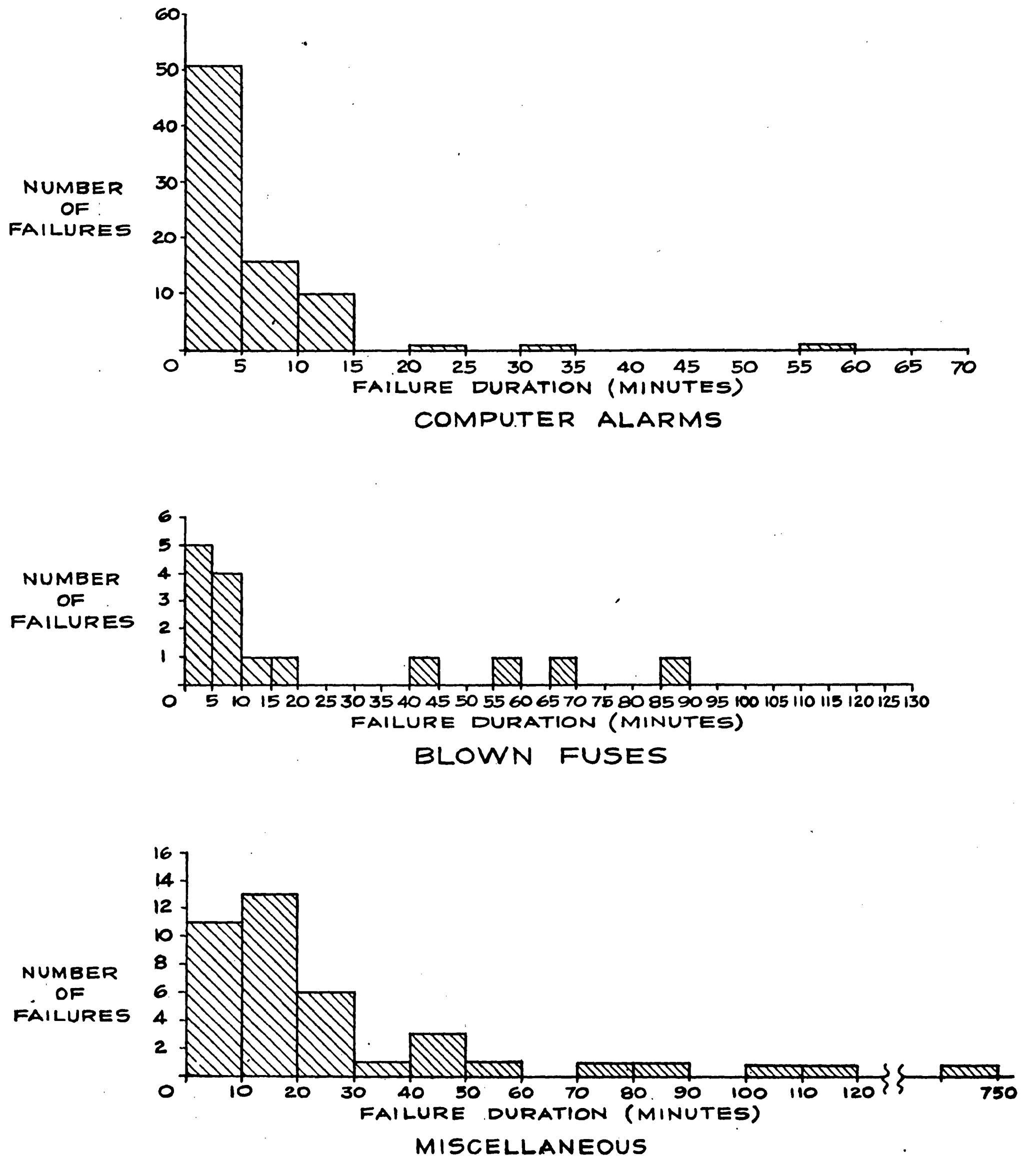

FIG 1

FAILURE — DURATION DISTRIBUTION
FOR DIFFERENT TYPES OF INTERRUPTIONS

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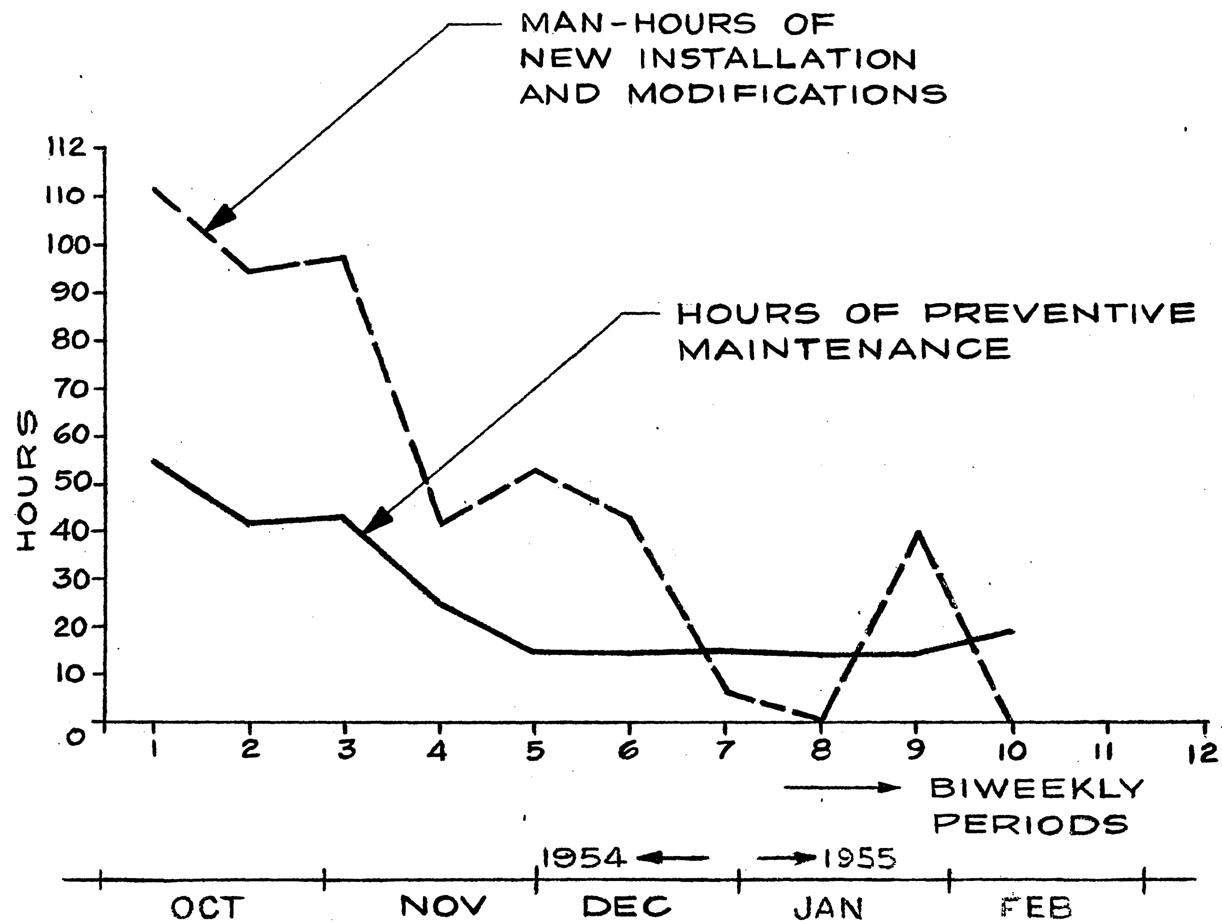

FIG 2

SUMMARY OF INSTALLATION AND MAINTENANCE WORK

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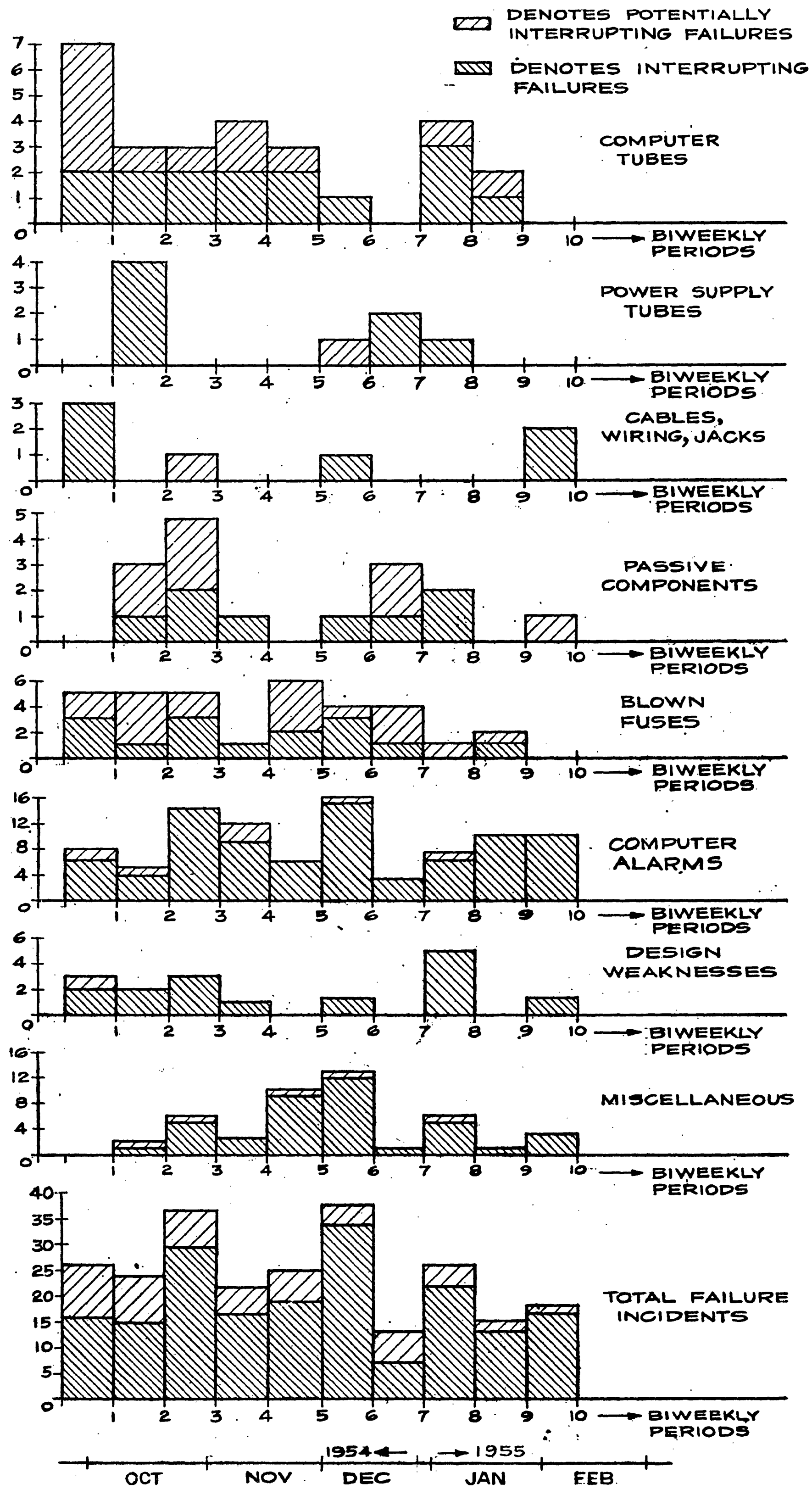

FIG 3

INTERRUPTING — FAILURE FREQUENCIES

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