SCHEDULING AGAINST A PROBABILISTIC DEMAND IN A HEURISTIC ENVIRONMENT

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PREFACE

1. This investigation is based squarely upon the conflicting beliefs at responsible levels of management that:

   a. Because electronic computers have enjoyed such phenomenal success in extending man's knowledge and capacity through compressing time and performance in otherwise impossible computational situations, they are, quid pro quo, adaptable as black box solutions in an iterative mode to any complex problem challenging human intellect or capacity -- such as that of scheduling resources to satisfy a random demand in a heuristic environment.

   b. There are some situations in which human intellect and heuristic judgments alone suffice to solve problems at hand.

2. The hypothesis contained within the proposal for research, Appendix A, adopts neither of these propositions per se but assumes they are on opposite ends of a continuum. The original hypothesis reads:

   > That there is a combination of human intelligence and computer application which may be assembled for most efficient handling of the Range [any complex] scheduling problem.

3. A series of procedural objectives were established as a positive guide for the research effort and as a means in at least one case of validating or invalidating the hypothesis. These procedural objectives were:

   a. To search for, identify and describe a complex scheduling operation in the real world involving random arrivals of "customers" varying demands for "service", decisions heuristically derived, and on which opposing points of view concerning computer automation sharply impinge.

   b. To conduct research of means for isolating the factors and their arrangement in the scheduler's mind of which he may not be aware but which are the real basis for his heuristic judgments.

   c. To develop algorithms containing the factors and which approximate such heuristic processes, and finally,

   d. To determine to what degree, if any, algorithms so evolved and computerized can be used to assist the scheduler in assuring safety of operations and achieving greater scheduling efficiency in terms of customer satisfaction, time, and resources.

4. The things inviting particular attention as subsequent parts of this thesis unfold are:

   a. That the procedural objectives have been accomplished in sequence with one reservation. The Range scheduling operation was modeled, programmed for the 1620 computer, and tested for its ability to duplicate a typical week's schedule produced manually by scheduling officers. The pilot model in active use will serve the purpose of establishing the man-machine combination best suited to over-all Range scheduling needs.

b. That the pilot model can be practically employed in its present form when the problem of ready accessibility to a computer facility is solved.

c. That the hypothesis as stated has been validated with the degree of machine automation remaining to be determined.

d. That, since many scheduling situations exist in our complex society in which heuristic judgments to varying degrees are the primary means of achieving successful operations, the experiences and findings recorded will have many direct or translational applications.

e. That important applications to the broad body of science have been made:

   (1) By focusing attention on not heretofore identified and published quasi-psychiatric techniques essential

to the algorithm seeker in successfully extracting from the mind of the scheduling decision maker the factorial basis for his heuristic judgments.

(2) By demonstrating that heuristic judgments can be approximated by algorithms which, in turn, may be employed to fix the degree to which computer automation may be used to supplement human judgment in successful solution of real world problems.

It is fitting at this point to acknowledge support and encouragement given and accepted from inception of my graduate program through preparation of this dissertation. For in the truest sense, no man stands alone, he is the sum of the people who influenced him. Humility should cause him to ponder just how much he is really responsible for setting his own goals and marking their achievement.

Gratitude is due to Major General Leighton I. Davis, Commander, National Range Division, and to Dr. George K. Hess, Jr., Chief Scientist of that organization; Mr. C. S. Showalter, Civilian Personnel Officer, Air Force Missile Test Center; Mr. E. W. Eads, Career Development Officer, and Mr. C. W. King, Civilian Personnel Officer, Headquarters, Air Force Systems Command, who supported my graduate program application and gave much needed encouragement from time-to-time.

Among significant contributors were members of my advisory committee, Professor W. J. Bentley, Chairman, Vice-Dean E. C. Burris, Professors H. G. Thuesen (Emeritus), W. J. Fabrycky, P. E. Torgersen, and R. A. Hultquist, who augmented my education and guided my doctoral program.

High regards to work associates John Michalski and Max Cleveland for acting as sounding boards for ideas and editorial criticism; Barbara Young for translating detail logic flow diagrams to a machine program; Ted Zimmerman for program editing and computer operation; and Eleanor Hopper for typing and thesis format control of preliminary drafts.

Appreciation is extended to Lieutenant Colonels M. M. Kovach and P. A. Tisdale for approving my involvement in the Atlantic Missile Range Scheduling Operations. Special credit is given to Major H. L. Peckham, Jr., Chief Scheduler, and his scheduling officers, Captain C. H. Hubbs, Captain R. S. McHargue and Captain P. N. Shull, for the many hours they contributed to discussions and their always helpful responses to the hundreds of questions resulting from my observation of and participation in the scheduling process.

This dissertation was completed in Stillwater, Oklahoma, where the services rendered in editing and typing the final draft by Velda Davis, and in proofreading by Carmelita Jones are recognized.

Finally, thanks are due my wife for the countless hours of typing and devotion on the home front in my

technical absence over the span of my graduate program and to God for guiding our lives.

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CHAPTER I

INTRODUCTION

This dissertation discusses research conducted over the period July, 1963, to April, 1964, relative to test scheduling at Cape Kennedy (Canaveral) for the Atlantic Missile Range. A predominant number of this nation's large missiles and spacecraft are launched from Cape Kennedy. An iterative manual sequencing and scheduling process is used. The objectives are to schedule tests to be run concurrently or in sequence precluding conflicts, assure safety of operations, and to maximize service to range users in terms of their requested test times and spatially distributed instrumentation requirements.

The over-all objective of research in this area was to develop a pilot model of actual scheduling operations useful in determining an optimal man-machine combination. A fundamental a priori objective was to determine whether considerations influencing scheduling decisions could be identified and structured in the form of algorithms reproducable by computer programs.

It is important, at the outset, to define terms used in the title of this thesis. Scheduling: The sequencing of commodities requiring service and assignment of arrival times at each facility involved to optimize an objective function and produce a desired product. In this thesis, commodities are missile or spacecraft launch or support tests, facilities are items or systems of test instrumentation, the objective function is to maximize service to the test range user (minimize or avoid queuing delay), and the product is test data. Sisson (1) in his chapter on <u>Sequencing Theory</u> draws a fine distinction between sequencing and scheduling assigning to the former "the order in which units requiring service are serviced (Churchman, 1957, p. 450)" and the latter "the time of arrival of units requiring service." This distinction suffers considerable compromise as Sisson presents and discusses the works of other contributors. In this dissertation, by definition, sequencing is assumed to be a procedure inherent in scheduling.

Probabilistic demand: This term connotes that the number of commodities arriving for service in any future time period is not known, but conforms to some probability distribution (2). It has been demonstrated that the arrival of missiles and spacecraft for testing is approximated by a Poisson distribution (3),

$$p(n:\mu) = \frac{\mu^n e^{-\mu}}{n!},$$

where n is the number of launches to arrive within a given week and μ is the average number of launches per week.

Comparisons between the statistics for each of five years running and cumulatively were compared with theoretical distributions. The chi-squared test was used to test the hypothesis that the theoretical frequency function was a satisfactory fit to the empirical frequency function. The Poisson hypothesis was tested at the 95% confidence level corresponding to a chi-squared probability of 0.05. In all cases the computed value of chi-squared was less than the critical value. Figure 1 is presented to show the fit of the actual data and theoretical curve. Figure 2 is presented to show the use of such conclusions in terms of prediction of future launch load which has a bearing on the size of the scheduling model to follow the pilot model developed in this thesis. The Poisson distribution results from the fact that many independent programs contribute to the launch workload and experience slippage, acceleration or cancellation, as they progress in time.

Heuristic Environment: Webster (4) provides some insight concerning the meaning of heuristic: "Applies to methods [of scheduling] which are persuasive rather than logically compelling." This definition in its brevity does not fit the circumstances involved in this thesis since it cannot be admitted that test schedules of missiles, spacecraft, and support tests are arrived at through persuasion. The Office of Aerospace Research, Bulletin 17, defines heuristic as "using the information obtained in one step of a solution to aid in deciding upon the next

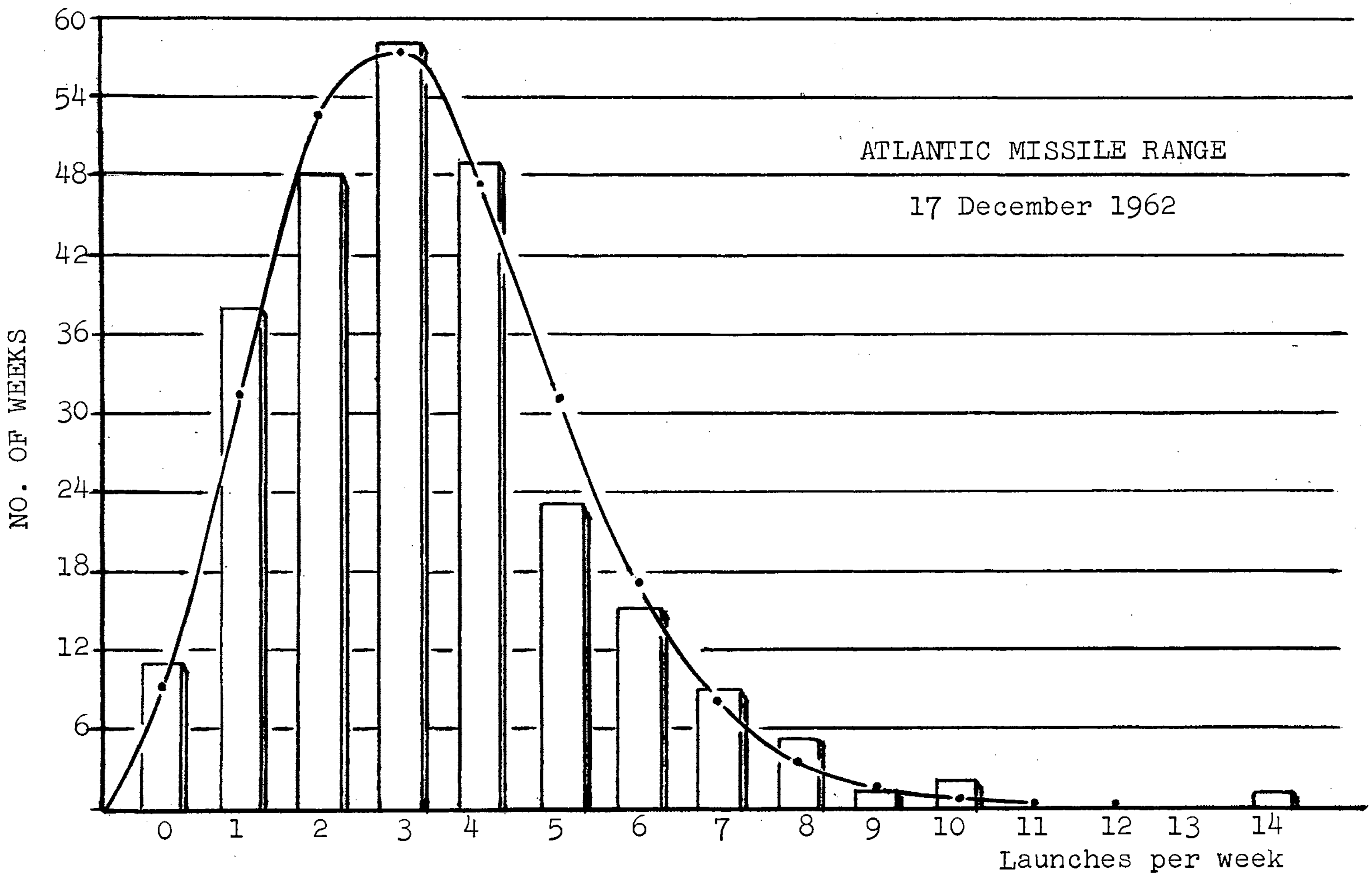

Figure 1. Poisson Distribution Fitted to Summary of Launch Statistics for FY-58 Through FY-62

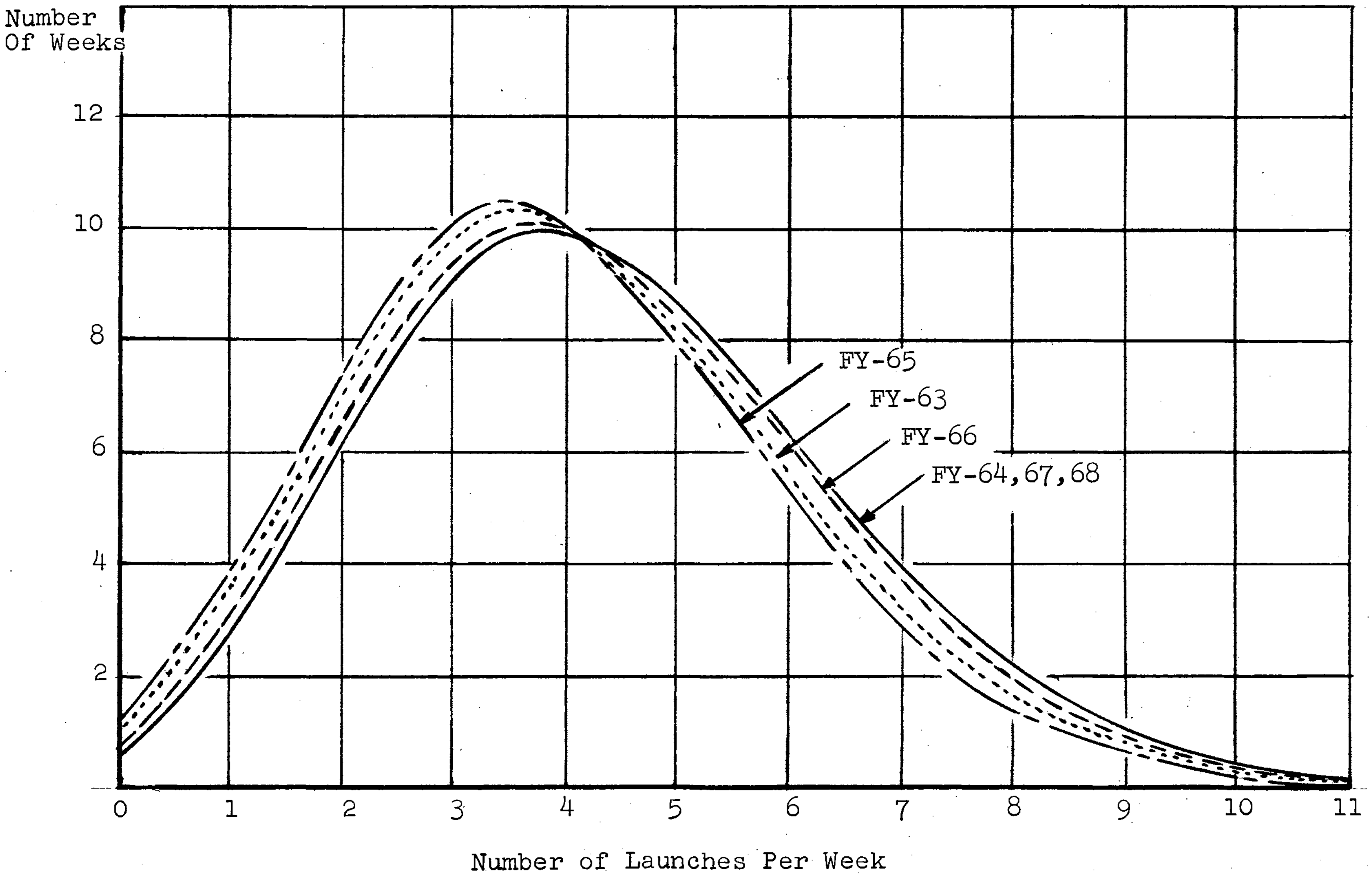

Figure 2. Poisson Distribution Fitted to Launch Data for FY-63,-64,-65,-66,-67,-68

step; it also means using a problem solving procedure that does not necessarily guarantee an optimal solution" (5). It goes on to say:

> "In the past, experimenters studying human information processing in complex tasks have been primarily concerned with algorithmic procedures. However, a great many of the problems people must solve in everyday life, and many military problems, require the use of heuristic procedures for one of the following three reasons: First, the person has no algorithma for solving the problem; second, there is only partial information present; or third, the cost in time or money makes the use of an algorithm unfeasible. Examples of problems where heuristics are often applied for one or more of these reasons are the scheduling of work by people and/or production machines, the stock market problem, the transportation problem, and the weapons assignment problem."

The bulletin may have included missile and spacecraft testing since the definition applies superbly to the actual environment in which such test scheduling is conducted. In research and development testing, the numbers of vehicles per test program, per phase of test program, and test objectives per phase and by serial number are identified at the outset in as much detail as possible for attainment of a desired operational status. However, numbers and objectives are altered in time and sequence to benefit from all prior test experience as the program progresses. Similarly the sub-system or support tests run between major launches vary in character, sequence, and number. These circumstances, combined with the relative national priority of programs, and other influences such as actual versus planned rate of achievement, imminence of the next launch, etc., create a highly complex heuristic environment in which scheduling must operate. Each periodic scheduling of tests is, to a degree, interdependent with and influenced by prior test schedules and their outcome, and, each periodic schedule is not necessarily optimal in terms of range time or instrumentation resources scheduled to maximize service to range users. It is this heuristically based scheduling decision process which the research described approximates by algorithms and a pilot computer program. The pilot scheduling program in evolutionary application will provide the basis for cost/effectiveness analysis and decisions concerning the optimum man-machine combination for accomplishing the range scheduling function.

In the process of defining the terms, one of the basic reasons for selecting the area of research for a doctoral thesis has been identified: The challenge represented by two opposing points of view. Though the opinions have been separated into two groups to aid understanding and discussion, it should not be concluded that opinions are necessarily bimodally distributed.

There are managerial and technical people outside the arena in which the scheduling process takes place who view it intuitively or through "classical lenses" as a job shop to which sequencing models and computers may be appropriately applied. They view scheduling automation as particularly desirable to reduce or eliminate absolute dependence on the art of scheduling and the talent possessed by a handful of schedulers on which the success of a multi-billion dollar operation and achievement of national objectives sharply impinge. Some of these do not resort to such concerns but view computer applications to management and operations as the popular way to go.

There are managers or operators associated with the scheduling process who are impressed with the heuristic environment in which scheduling operates, its "ifiness", and large number of interdependent alternatives. They believe that scheduling "can't get there" by machine processes. Their attitudes varied from passiveness concerning the proposed research effort to open invitations with reservations that inherent complexities could preclude a practical product.

A high percentage of all concerned, however, adopted the commendable point of view that the research effort was worth the try. It is worthy of note that Appendix A, the original proposal for research, has on its front cover an uninfluenced and unexpurgated reaction to the proposal for research in the area of scheduling. The individual involved has been one of the most cooperative from the outset, and indeed, has been the prime source of encouragement and participation without which this thesis would have been impossible.

An early attempt was to employ one of the first principles of scientific inquiry -- search of the literature -- to identify any prior publications which would aid in tackling the then speculated features of the scheduling problem.[1] This initial approach was more productive in its negative rather than its positive results. Perhaps this result can be correlated with conclusions reached by Schaeffer (6) in his treatise on The Logic of an Approach to the Analysis of Complex Systems. Following an intriguing monologue replete with convincing references to and quotes from renowned scientist and philosophers he concludes that the objective of science is the development of theories which describe the "world", while the objective of systems analysis is the formulation of adequate solutions to specific predesignated problems. He further concludes that the methods of science and systems analysis, though not opposed, differ in four major respects: In terms of definition of fact and verification "the system analyst's greater concern is to arrive at an answer -- any answer being better than none -- and his lesser concern with a rigorous methodology." In terms of fact selection and prediction, the systems analyst's concern is "with specific truth applicable to one time events in contrast

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[1]E. Bright Wilson, Jr., An Introduction to Scientific Research (New York, N. Y., 1952), p. 10: "Six hours in the library may save six months in the laboratory." "Instead of the unattainable ideal of completeness, there are two goals which are usually important and feasible. The first of these is to find out if the information which is the object of the proposed research is already available. The second is to acquire a broad general background in the given field."

to the scientist's concern for general truth applicable to an infinite set of events." While the distinctions made are relevant to the research described in this dissertation, Schaeffers' forced separation of scientific method and systems analysis for purposes of argument obscures the fact that Systems Analysis, Operations Research, et al., though not presuming to put on the mantle of science, are continuously engaged in bridging the gap with a methodology to solve a particular problem and extend knowledge beyond one-time events subjected to study.

A logical decision was made to embrace the scheduling problem by actual participation in scheduling procedures and use the resulting experience for bracketing the type and extent of literature search best suited to the needs. In the pre-involvement literature search and subsequently, it became increasingly clear that the area of research selected was untrammeled and, therefore, that any achievement would clearly make a unique contribution to the body of applied science.

Relative to the above, Ackoff (1) presents prime bibliographical sources and reviews the chronology and most advanced status of scheduling and sequencing models. An examination of Chapter 6, Dynamics of Operational Systems: Markov and Queuing Processes, by Morse, revealed that its contents were not particularly applicable to the actual scheduling problem being addressed for three reasons. One is that the philosophy of the range in scheduling to achieve maximum service to the range user (minimize or avoid queuing delay) is antithetical to queuing theory which assumes queuing as desired to achieve some other objective function such as minimum cost, maximum profit, etc., not particularly compatible with national missile and spacecraft testing objectives. The second is that queuing theory and practice assumes models whose parametric values are determinable and repetatively useful in solving real world problems. A third is that the most astute of queuing models appears to fall short of the inherent complexity of the scheduling situation studied. This is not to say that Morse, if he were actually involved, could not make significant contributions in those cases where queuing is unavoidably admitted in the scheduling process, but that fine mathematical instruments involved in queuing theory are not compatible at this time with the applied research methods adopted for tackling the actual problem.

An examination of Chapter 7, Sequencing Theory, by Sisson (1) revealed a very orderly and succinctly exposed number of sequencing models and the impact which computers could have in translating some of the more astute ones from laboratory to practical use -- particularly in cases where simulation is employed. He reports:

> Finally, in the more complex cases, several researchers reported the use of general simulations (approach C). Jackson has done this for one-machine cases with complex objectives (case I, Table 7.1). Rowe (1959) in particular has published results, and other groups

> are working along similar lines. These efforts are laboratory experiments and are not always intended to optimize but to give insight. One experimental procedure has been to simulate the sequencing procedures from a specific shop (where they can be determined) and to show that the simulator will predict the shop activity. Then, using a "better" procedure, the simulation is rerun and shown to give what would be better results in the actual shop. Dr. W. E. Barnes, of General Electric Schenectady (letter, August 4, 1959), using Rowe's approach, reports, 'Some of the sequencing techniques under study here have been tried in a job shop of another General Electric Department. No results have been released, but in general they prove (the) validity of simulation and improved the scheduling of the shop.'

Simulation of the scheduling operation is not a desired approach nor the objective; actual (or proximate) modeling is. Further, the job shop routine is a relatively "clean" operation compared to the heuristic environment in which the scheduling and execution of missile and spacecraft tests are performed.

Concerning sequencing models in general, Sisson (1) in the first part of the chapter says:

> Every researcher abstracts or assumes his own model. First, we will present a model which is more general than any considered by many researchers active in the past two years from which logical (not simulation) deductions have been made. We can then discuss various simpler versions of this model, which have been analyzed, and also discuss the ways in which real sequencing situations are even more complex.

The principal assumptions made on the model are as follows (Sisson, 1959, p. 3, and Giffler, 1959, p. 1):

1. No machine may process more than one operation at a time.

2. Each operation, once started, must be performed to completion.

3. A commodity is an entity; that is, even though the commodity represents a lot of individual parts, no lot may be processed by more than one machine at one time.

4. A known, finite time is required to perform each operation and each operation must be completed before any operation which it must precede can begin.

5. The time intervals for processing are independent of the order in which the operations are performed.

6. Each commodity must be processed by a designated sequence of machines, this sequence being also called "the technological ordering" or "the routing."

7. There is only one of each type of machine.

8. A commodity is processed as soon as possible subject only to routing requirements given above.

9. All jobs are known and are ready to start processing before the period under consideration begins.

10. The time required to transport commodities between machines is negligible.

11. In-process inventory must be allowable (Wagner, 1959, p. 131).

Translating machines as test instrumentation, and commodities as tests required, it was determined that 9 of the 11 characteristics of models discussed cannot be allowed in the missile and spacecraft testing activity due to the heuristic environment and floating parametric values characteristic of such activity.

Thus, the ability to identify models described within the chapter even of the more astute types which could be applied or adapted to the scheduling operation under study met with little success. The leading sentence, however, is significant: "Every researcher abstracts or assumes his own model."

An Armed Services Technical Information Agency (ASTIA) bibliography on Operations Research (7) was used.[2] Several publications which may have been fruitful are listed in the selected bibliography of this thesis. In general, they dealt with rather limited or classical examples of the job shop. In those cases where heuristic properties affecting scheduling rules were embraced, they turned out to be rather basic expositions related to classical problems such as that of the traveling salesman.

Churchman, Ackoff, and Arnoff (8) discuss the nonanalytic solution of allocation problems to show that judgment and experience can be used to solve problems involving a small matrix to arrive at more timely and improved solutions that may otherwise be expected. The achievement of optimality with reference to some criteria, however, was demonstrated to be a difficult and unachievable goal abrogating timeliness and human capacity as the matrix size increases beyond some size, say 15 x 6. Such nonanalytic solutions assume linearity and known parameters neither of which are applicable in the scheduling process

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[2]ASTIA now the DDC -- Defense Documentation Center for Scientific and Technical Information. DOD Instruction 5100.38, dated 19 March 1963.

studied. Churchman, et al., point out that frequently a major difficulty is the derivation of data to make up such a matrix. They also emphasize that, though computers may be able to solve large allocation problems, the dynamics of the job may preclude their use; that is, lack of immediate access to or cost of machine time which may exceed intended savings sought through dedication to optimization. These are significant points relative to the model presented in this dissertation. It is demonstrated that computers may be used to schedule missiles, spacecraft and related support tests. Efficiency gains over human ability in terms of the optimum man-machine combination are discussed in Chapter V.

Having searched the literature of academic and published paper origin, the search turned inward to unpublished documents resulting from government contracts or originated by government research bodies which had a direct bearing on the problem at hand.

The title of the first of these clearly identified its objective: Operational Automatic Scheduling Information System (OASIS) (9) (10). This costly study and installation contract resulted in a computer center at Point Mugu, the Navy Control Center for the Pacific Missile Range (PMR) which, indeed, automatically prepares and dispatches missile launch and support test schedules. Significantly, the system, though automatic, publishes schedules <u>after</u> they have been prepared by human schedulers in much the same way as performed at Cape Kennedy, The Atlantic Missile Range (AMR). The major difference in PMR and AMR scheduling is in collation, printing and distribution of the manually developed schedules. At the PMR, the Computer Center serves this function. At the AMR a typewriter and messenger service performs the function. It was intended that the OASIS system would eventually actually perform scheduling operations or, in retrospect, to a degree indicated by analysis of the optimum man-machine combination. Partial or complete automation to solve the scheduling problem at the referenced location does not exist at this writing.

Access was provided to another unsolicited study and proposal by a systems development contractor who exercised proprietary rights over its contents (11). The proposal describes generally what to do to achieve automatic scheduling at the PMR and identifies several obvious files in memory storage which would be required to play the computer scheduling game. The presentation is based on the "outsider" point of view previously referred to, identifies the problem but is deficient in providing a blueprint of how to effect a solution.

A third reference is a Pacific Missile Range Operations Research informal note "On the Use of Computers in the Range Scheduling Process" (12). The author discovered this note after his enlightening involvement in the AMR scheduling processes had resulted in appreciation of the problem and formulation of a plan of attack. The findings in the referenced note in many instances parallel those of the author so far as identifying the features of the problem but are not pre-emptive. While a high regard for the paper is freely acknowledged, it served only as others in the series referenced above, to identify some elements of the problem -- not to develop actual approaches or means for solving it.

For instance, Frisbie, et al., (12), conclude that, assuming the gap between a classical model and a unique model representing the real world scheduling problem could be closed, it would not be feasible to solve such a model by the methods of linear programming, integer linear programming or complete enumeration. They go on to say that not only would the solution of such a mathematical model be a formidable task but a major obstacle to the use of such otherwise neat mathematical methods would be the "value system" in scheduling. The value system discussed is synonomous with the "heuristic system" of subjective judgment to which this dissertation has made frequent prior reference.

The method of total enumeration was considered because it is the only known method for finding an optimal initial schedule for the Range when all the physical factors are included. This would be a task involving number manipulations of astronomical proportions. If it is assumed that 100 vital resources such as various instrumentation systems, ships, aircraft, frequencies, etc., are to be scheduled and that the investigation of each resource for each operation will require three elementary digital computer operations, then the total number of computations necessary to evaluate a possible schedule containing k of the n requests for operations is 300 k. Continuing this reasoning, it follows that the total number of elementary operations which are required to evaluate all possible schedules is:

$$300 \sum_{k=1}^{n} k \binom{n}{k} k! = 300(n!) \sum_{k=1}^{n} \frac{k}{(n-k)!}$$

$$\approx 300\, e(n-1)n!$$

Some appreciation of the magnitude and infeasibility of this approach to the problem in terms of IBM 7090 computer time required for various values of n are shown below:

Number of Operations	Computing Time for IBM 7090 Digital Computer
5	2.0 seconds
10	1.5 days
15	2.4 years
20	6 billion years*
30	1.0×10^{24} years
40	4.1×10^{39} years

*Approximate age of solar system.

Frisbee, et al., (11) refer to an article by Teager. Teager (12) proposes that man and machine may work together via suitable communication links to arrive at an educated intuitive solution to such a problem as scheduling. Properly designed, the system could work much more efficiently than either man or machine independently. Teager summarizes capabilities of man and machine as follows:

1. A Computer

    a. Possesses perfect, rapid recall of a very large quantity of precise bits of information.

    b. Performs simple operations in logic and arithmetic very rapidly.

    c. Can efficiently produce continuous logs of all states and actions of the whole system of which it is cognizant.

    d. Can efficiently summarize and collate large quantities of data, such as can be obtained from the continuous logs of states and actions.

2. A man

    a. Can make heuristic decisions (i.e., decisions based on less than total information and/or less than perfect logical operations).

    b. Can decide which contradictions are not meaningful for particular operations.

    c. Can be illogical (can be an advantage or a disadvantage).

    d. Can recognize abstract patterns and consequently may be able to quickly eliminate many unsuitable schedules.

    e. Communication with man is generally easier (i.e., more natural) but less precise.

In summary, it is reasonable to assume that a man-machine system for scheduling would employ machines as a large memory aid and for executing rapidly many logical processes including arithmetic operations to check for conflicts and to include as many programmed judgment factors as can be approximated by appropriate algorithms. The system would use human beings to reduce the number of combinations and permutations of tests and equipments to reasonable proportions so that the advantages of enumeration of the remainder may be practically employed. The system would reserve for the human scheduler final judgments which cannot otherwise be anticipated or feasibly incorporated.

CHAPTER II

THE DESCRIPTION OF A COMPLEX SCHEDULING PROCESS INVOLVING PROBABILISTIC DEMAND AND HEURISTICALLY DERIVED SOLUTIONS

The Atlantic Missile Range consists of a launch area, (Cape Kennedy, Station 1), many mainland instrumentation sites, a series of down range instrumentation stations on islands and the continent of Africa, transportable vans, and mobile shipborne and airborne instrumentation stations as required. See Figure 3.

Figure 4 presents an over-all view of land areas involved in AMR launch operations. Figure 5 presents a typical listing and location of types of instrumentation on Cape Kennedy, Station 1. Figure 6 lists and shows the location of typical mainland instrumentation associated with Station 1. Figure 7 lists and shows the location of instrumentation on a selected down range station.

The Atlantic Missile Range (AMR) is developed, maintained, and operated for the Department of Defense (DOD) by the United States Air Force (USAF). The administrative organization is the Air Force Missile Test Center (AFMTC)

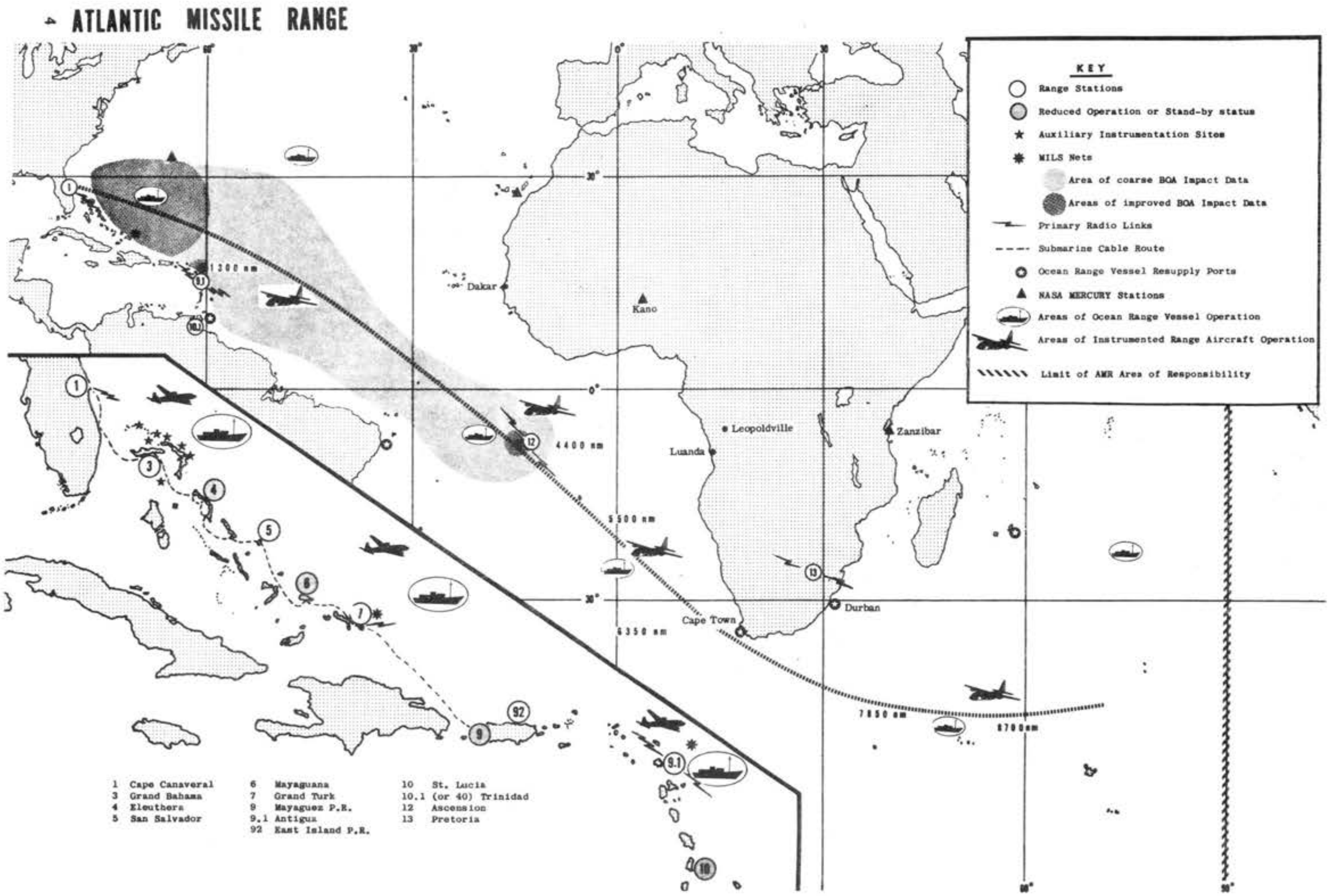

Figure 3. The Atlantic Missile Range (AMR)

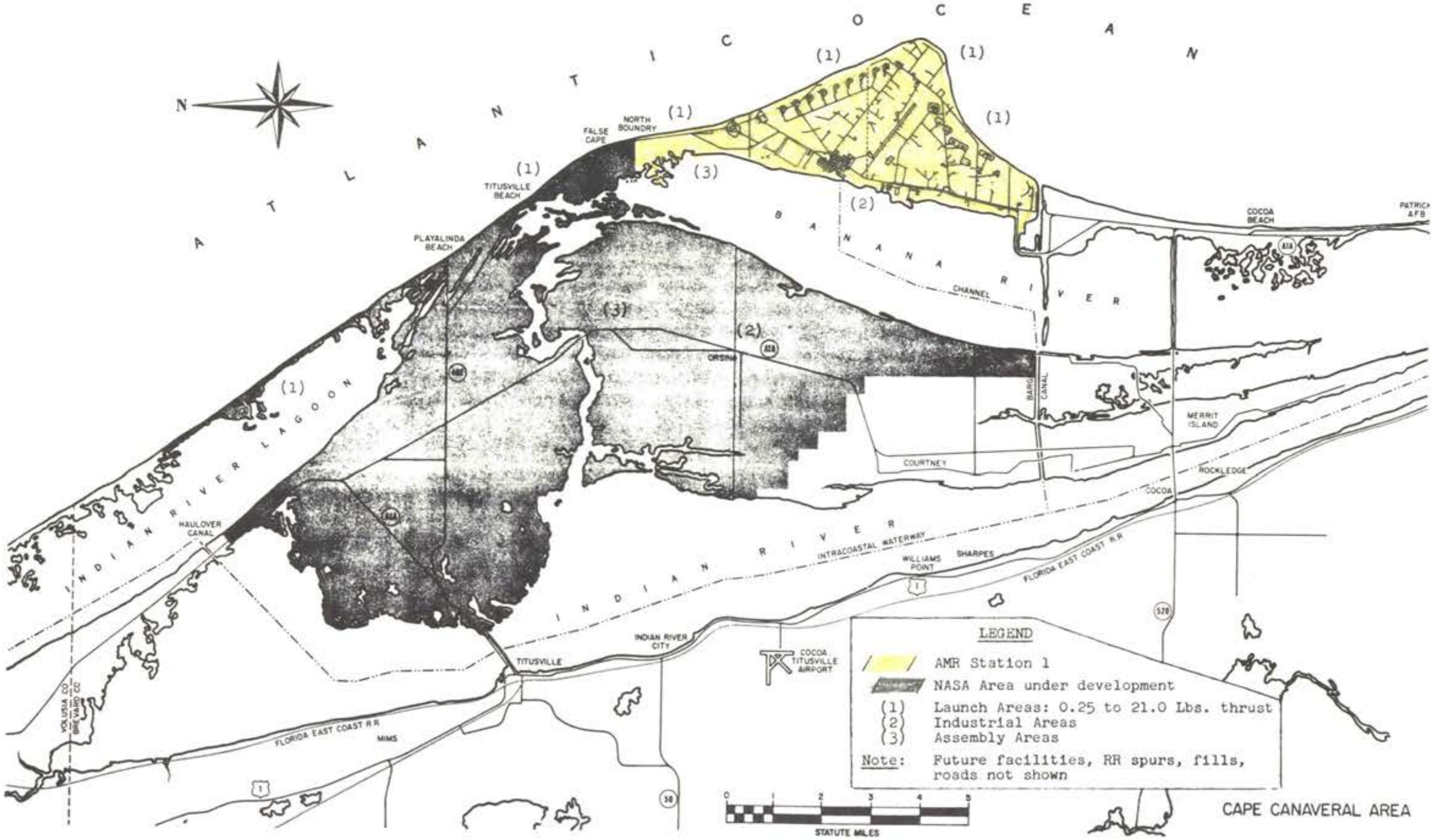

Figure 4. Over-all View of Land Areas Involved in AMR Launch Operations

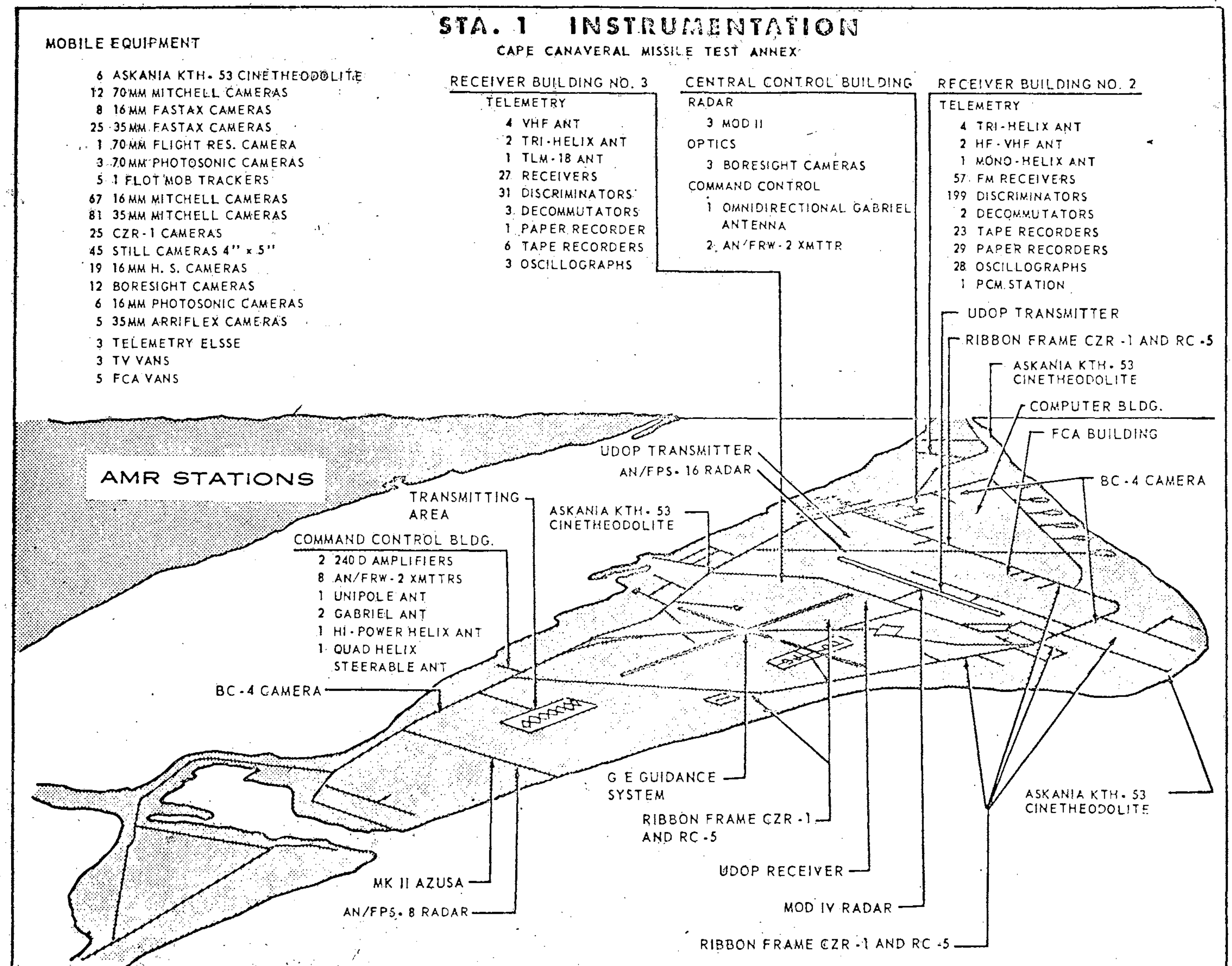

Figure 5. Typical Listing and Location of Instrumentation, Cape Kennedy, Sta. 1.

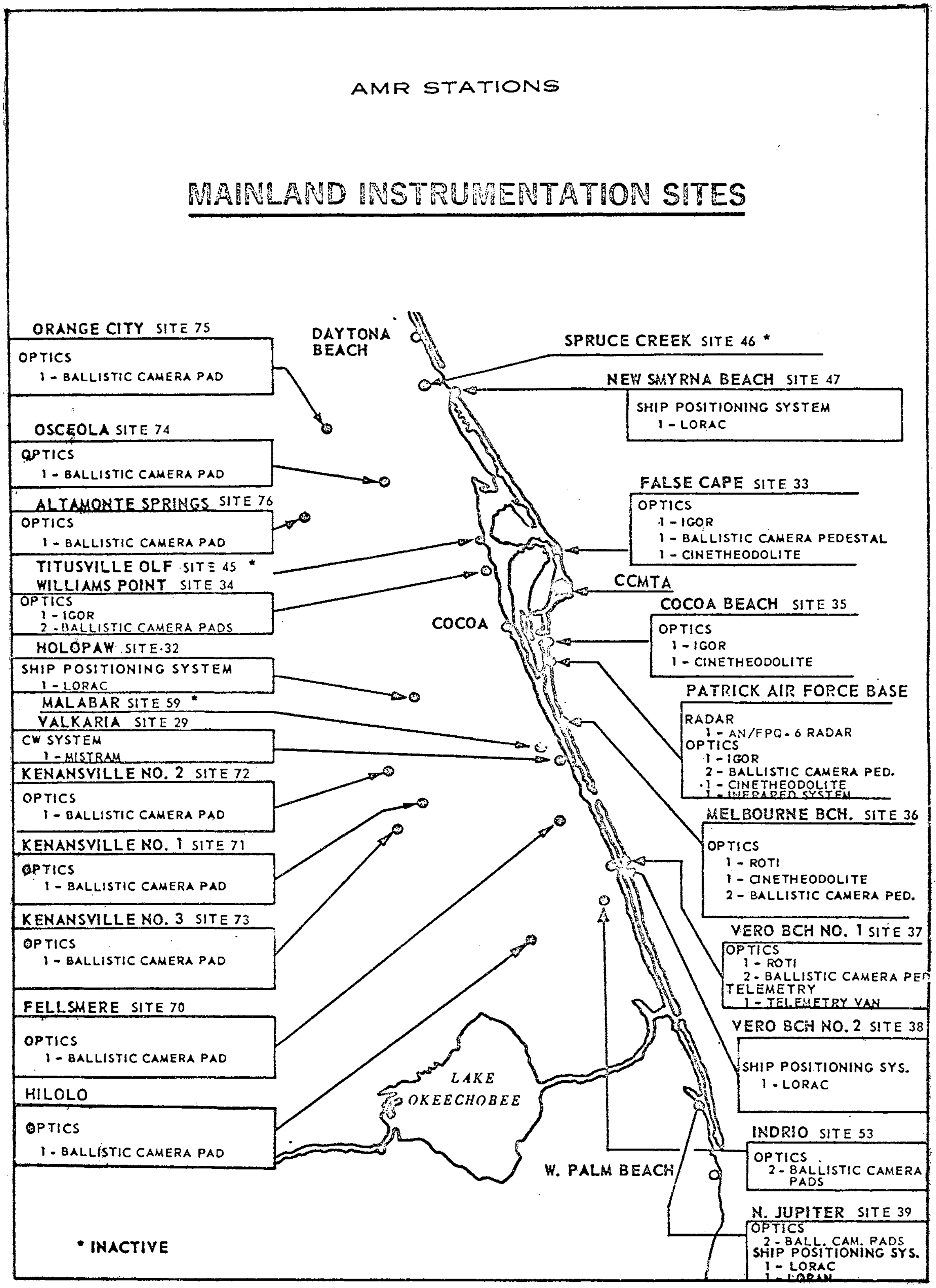

Figure 6. Typical Mainland Instrumentation Associated with the Station 1 Complex

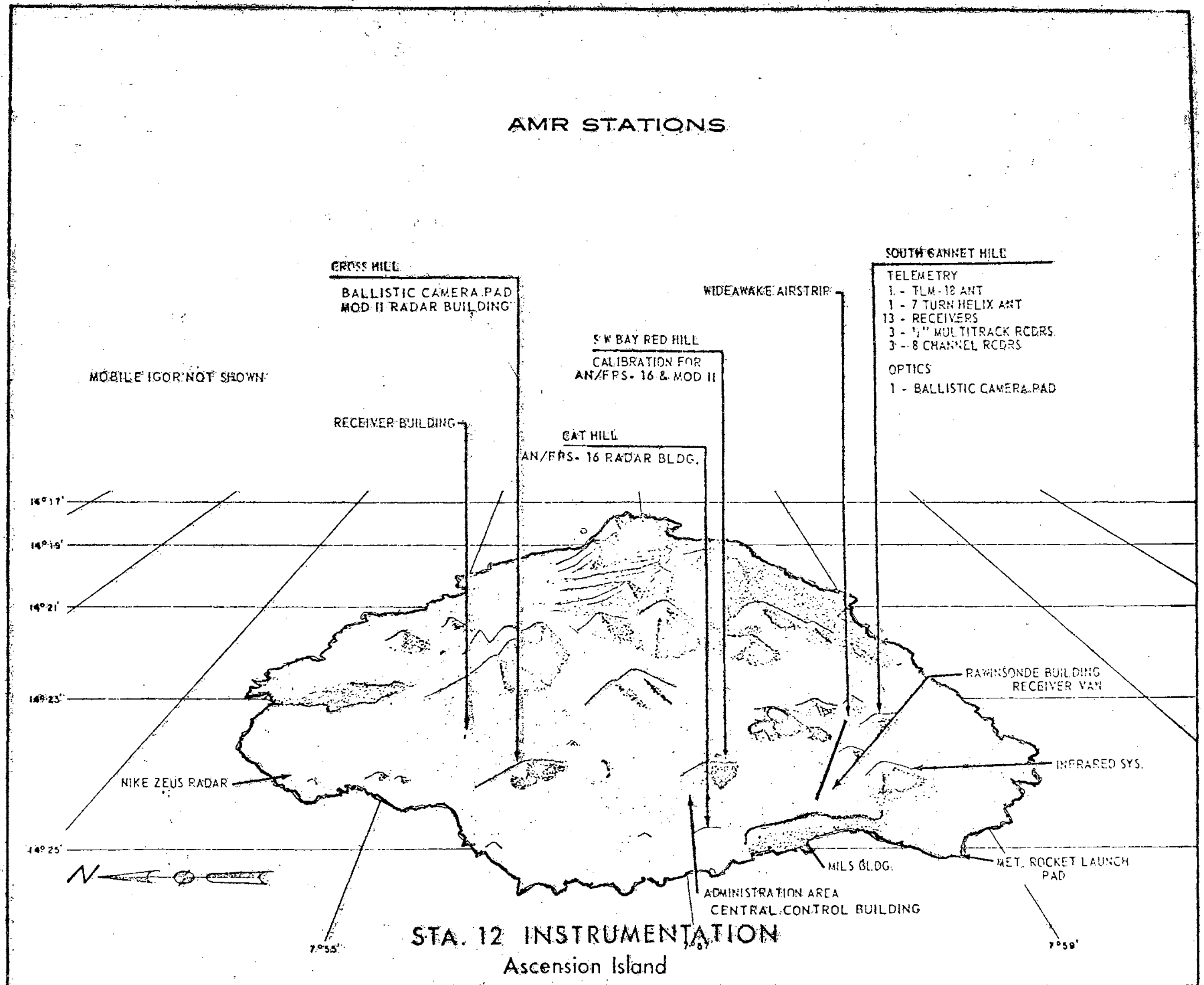

Figure 7. A List and Location of Instrumentation on a Selected D/R Is. Sta.

located on Patrick Air Force Base (PAFB) approximately 15 miles south of Cape Kennedy.

Range users, primarily the Armed Services and NASA, having received approval or coordination of proposed programs to involve the AMR, make first official contact with the AFMTC by submitting a Program Requirements Document (PRD) couched in technological terms. The AFMTC responds with a Program Support Plan (PSP) which identifies abilities and inabilities to satisfy technological requirements. Negotiations proceed for funding, developing and installation of additional instrumentation to meet jointly resolved requirements in the projected time period. An Operations Requirements Document (OR), in much more detail than the PSP, follows from the range user and, based on it, the AFMTC prepares an Operational Directive (OD). The OD identified the types of tests, their number and general distribution in time, and specific equipment arrays required. The range user in due course submits a Test Schedule Request (TSR) by Wednesday of the week preceding the week in which he wants a test run. He identifies such tests by OD number and requests a particular day and test start time, S-Time, or T-0 time if countdown is involved. The sequence described above is diagrammed in Figure 8 with the area of research emphasized. A typical test request line entry as insterted on the scheduling board appears on page 29.

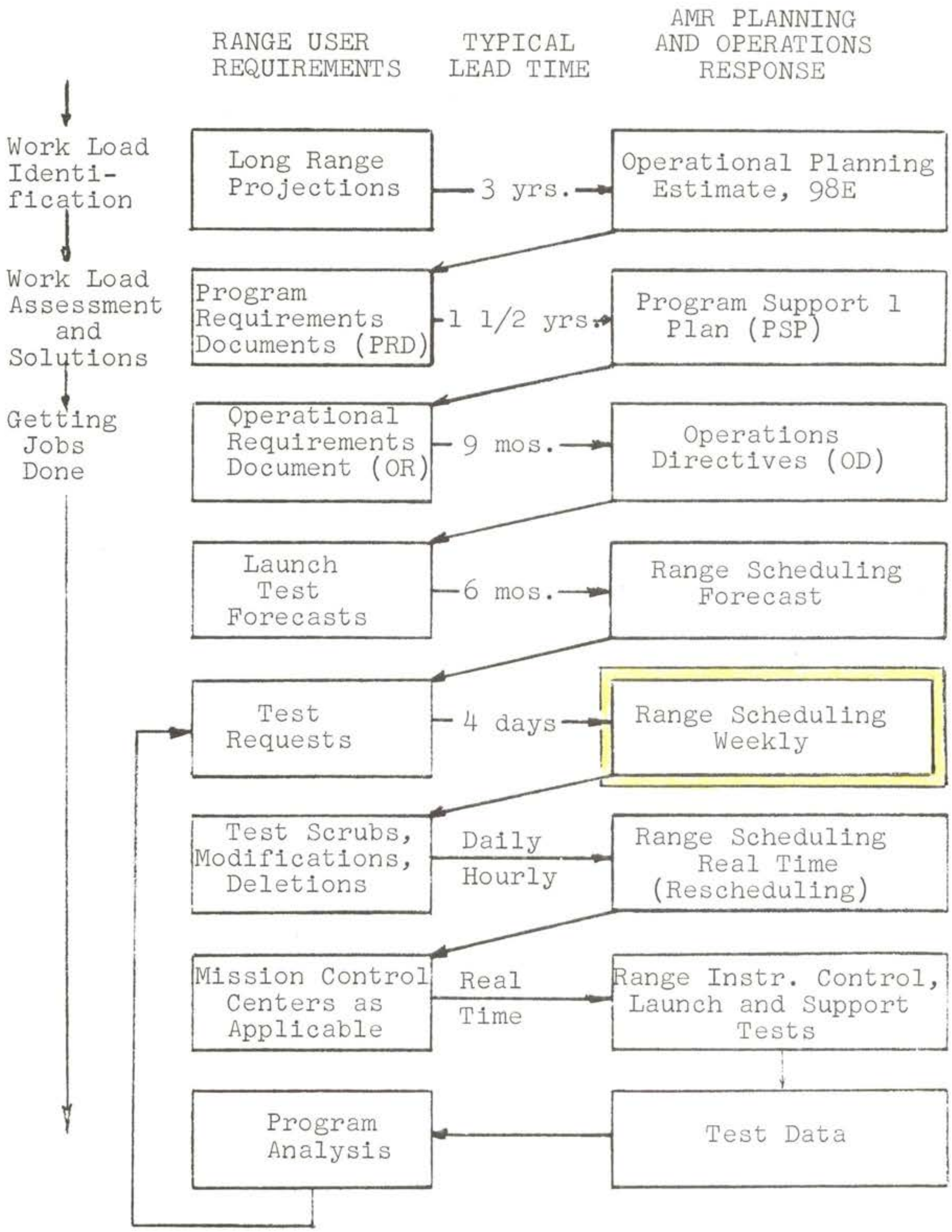

Figure 8. Flow of Documentation from Program Concept to Receipt of Data With Emphasis on the Scheduling Function

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The scheduler accepts TSR's for the following week up to 1,000 hours on the preceding Wednesday. He performs his sequencing and assignment function identifying and resolving conflicts in the process. He then coordinates the proposed schedule in assembly with range users on Thursday and publishes and distributes the result as a schedule for the next week. A declassified section from an actual published schedule is shown in Figure 9. Many scrubs, additions, and modifications of tests are requested and occur in real time during the active week and are accepted as is, shifted to open slots, or denied to maintain "no conflict" schedule control. The cycle repeats itself weekly.

General knowledge of the flow process from program identification to ultimate submission of test data to the range user was possessed by the author at the time he became a participant in the scheduling process for research purposes previously described. The fact that scheduling could be broken down into three phases, Forecasting, Weekly Scheduling, and Real Time Scheduling was one of the early significant results of actual observer involvement in the scheduling process. This identification permitted the logical concentration of research effort on the Weekly Schedule phase.

ATLANTIC MISSILE RANGE

(U) **RANGE OPERATIONS SCHEDULE**

WEDNESDAY 11 DECEMBER 1963 (0001-2400Z) CONTINUED

SECURITY CLASSIFICATION
Not Classified.
Classified only when in Cumulative Form.

TEST DIR.	OPERATIONS DIRECTIVE	TITLE	GREENWICH MEAN TIME	ACTION	REMARKS
3787	1105 PER REV 38	TITAN II LAUNCH	T-2000Z		Msl N-29, Pad 15, 130' ct. Lch Az 85°, Flt Az 106°. Mk VI Mod 2A R/V w/ 1 TLM link on 247.3 mcs. 60' BIH @ T-20'. SP POD. One recoverable staging camera. SOFAR, C-bcn. Sta 12 Mils net. Delete BOA. 2 C-130 TLM acft stage Sta 12. ARS SA-16 & C-54 stage Sta 3 and 2 C-130 acft stage PAFB for camera recovery. ORV UNI.
8495	008	DRO Spec Test	T-2000Z		w/3787. Spcl bfg #56. Sites U75R6 & U44R79 w/Ctdown boxes. At site U44R79, add 150ft extension & battery pack.
8496	009	A/B Rad Mon	T-2000Z		w/3787. C-131 acft T/O PAFB @ T-60'.
8493	098D	NIKE SMOKE ROCKET LCH	T-1930Z		Pad 43D. 60' ct.

SECURITY CLASSIFICATION		PAGE 4 OF 10 PAGES	MT
Unclassified	RCI-MT-R 1	COPY NO.	DATE: 05 DEC 63

AFMTC FORM JUN 62 44 PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE.

Figure 9. A Segment From an Actual Published Schedule

This step to narrow and bracket the problem deserves emphasis at this point because it was the first of a series which would obviously be required to reduce the area of research to manageable dimensions to fit the urgency for a solution and computer capacity available for model development. It was conservatively estimated, based on knowledge of the cost of systems development contracts and resulting computer installations, that a 15-man year effort and computer storage capacity many times that available would be required to put all range equipments in active inventory and equipments called out by active OD's in memory for machine manipulation in a fully automated scheduling model.

Further, such extensive effort and cost would be based on the outsider point of view that extensive automated scheduling (and other uses of the system) were, ipso facto, feasible and warranted. One of the prime objectives of the research effort described in this dissertation was to develop a pilot scheduling model for investigating such feasibility and for use as a tool in cost/effectiveness analysis of the optimum man-machine combination for scheduling applications.

To further confine the area of research while allowing little compromise with realism, a 95% rule was adopted. It was arranged with the Chief Scheduler that only those instrumentation classes, frequencies, communication links, and stations which were the source of 95% of his scheduling conflicts would be identified for inclusion as inventory in the pilot scheduling model.

As a result, seven classes were selected containing 13 items of equipment or components out of 44 for inclusion in the scheduling model. The remainder were excluded. By similar evaluation, equipments and systems on down range stations were excluded from the model since tests requiring the use of down range stations only were concluded to cause conflicts in the scheduling process only rarely. Therefore, Station 1 and Station 0 (PAFB) and seven classes of resources were to be included in the model. A provision was to be incorporated in the scheduling model, however, to preclude scheduling of tests involving down range stations only when they were in time conflict with launches since major launches invariably involve nearly all down range facilities and instrumentation.

Another logical restraint adopted to reduce the magnitude of the modeling job to manageable size without significantly affecting its practicality was the restriction of the model to a typical week. Thus, those classes of instrumentation, frequencies, communications, and stations required by support test OD's active during the selected week were to be considered as representative of the total range inventory. Even with this restraint, a preliminary estimate of the total number of unique items of equipment to be involved totaled 124. It was estimated that the making up of a computer "clock" file to record the in/out status (availability) of 124 items to be scheduled against requirements of support test OD's involved in the selected weeks activity would absorb approximately one-third of the 40k memory available in the IBM 1620 computer accessible for developing the pilot model. It was also estimated that various other "files" would absorb at least another one-third of the memory leaving a maximum of one-third for the complex scheduling program itself. Since the scheduling problem at this point had been reduced to a bare minimum without sacrificing its potential to represent the actual scheduling process when modeled, it was decided to proceed on this basis and use multiple passes in the 1620 computer if required. This technique was to be avoided, however, if at all possible in the interest of a single pass so that the scheduling program would operate as an entity from test request input to "no conflict" Weekly Schedule output -- the final test.

This preliminary stage of planning concerning the character of the scheduling model was the product of several weeks of participation in or exposure to the scheduling process. The experience also validated the early suspicion that the modeling of the scheduling process would not be so straightforward as was often concluded by those having the outsider point of view. This outsider point of view rested its case on the conclusion that range equipments were obviously known and OD test requirements were specific -- making it necessary only to have access to a computer of sufficient capacity and to develop a program to "beat" requirements against availability to arrive at a logical "no-conflict" schedule.

It is important at this point to review certain observations many of which indicated that the OD's in reality were in many instances only good departure points for scheduling as practiced.

In a given week it was observed that two support tests from two given programs had requested test times which overlapped -- not an unusual occurrence since frequently tests are scheduled concurrently. In this case the scheduling officer selected and contacted one of the test requesters (say program officer "A") asking him to slip his test to clear the time conflict. Receiving approval, the tests were scheduled in sequence. Questioned concerning this step, the scheduling officer revealed that both tests required the use of a one-only item of equipment -- that both could not be served simultaneously. This experience and the respective OD's were recorded in notes as a ground rule.

On a later week it was observed that these same two tests were requested and that their T-times again were in conflict. In this case the scheduling officer scheduled the tests in conformity with the test times requested! When reminded of the prior week's ground rule and action relative to these two tests, he explained that one of the test requesters had "deleted" the requirement for the previously critical one-only item of test instrumentation. He further explained that the remainder of equipments called out were not in conflict. He expanded further by stating that if the equipment had been in common demand, there was sufficient inventory to permit simultaneous scheduling. This "if" situation was recorded as a special case which would have to be managed by the proposed model if it were to play the game realistically. Again, this experience was recorded in notes and the respective OD's studied.

On yet another week, the two tests under discussion arrived on the schedule with conflicting T-times and no deletion of the critical one-only item of equipment by either. The scheduling officer proceeded to record the tests for running in obvious conflict. Questioned again, he explained that the vital piece of instrumentation involved was to be used on both tests on a "readout" basis. This meant that there was to be a random demand during the test intervals recorded for each test which could be controlled by the Superintendent of Range Operations (SRO) on a non-interference basis. Thus, simultaneous use could be avoided. Therefore, another "if" circumstance was recorded.

On yet another week, the same T-time-request-in-conflict situation arose relative to the two tests under discussion. In this case the scheduling officer contacted one of the test requesters, in this case program officer

"B", and asked him to slip his test out of conflict with test "A" -- a reversal of the first observation in this series. Questioned, he explained that test "A" had priority this week for the critical item of equipment, whereas previously, test "B" had had the priority. When questioned concerning the documented source of such priority reversals, he explained that support test "B" in the former case had priority because it was associated at that time with an imminent launch test; that the reverse was true in the latter case. Further, it was revealed, that one of the support tests was associated with a missile program which had a DOD priority of "1", duly documented, and that the other had an assigned DOD priority of "2". Since the DOD priorities are published to give a fundamental preference rating in all matters of support testing or otherwise, one of these decisions appeared to be in violation.

This discovery of floating and seemingly contradictory priorities, sharpened the observer sensitivity of the author. He was able to record a host of other apparently conflicting actions taken in the scheduling process. By meticuously recording and studying these anomalies over a period of several weeks, a pattern appeared to emerge which indicated scheduling officers were using a "shadow" priority system of considerable depth to accomplish their no-conflict (or allowed conflict) schedules.

An initial reaction of scheduling officers to this proposition was that they were not fully aware of their use of a priority system as such. A second reaction was that, apparently being so, the basis for the priority system could not be initially described except as the product of experience. It was decided that this proposition and the evidence deserved particular attention. Several special sessions were arranged to satisfy the mutual interest of all concerned.

Questions were developed preceding each session to guide exploration of the individual and collective experiences of scheduling officers to reveal the origin of the apparently conflicting scheduling decisions and the suspected priority system at play.[1] In the process a host of other factors and combinations of factors giving unique properties to scheduling decisions were identified and catalogued. Some of these have been mentioned previously. All were followed to a logical source. Another was the "substitution" rule which applies to some particular tests (OD's). In these cases, if the prime equipment called out

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[1]Thomas Fansler, Creative Power Through Discussion (New York, N. Y., 1950), p. 149: "The method of scientific inquiry also follows a general pattern, a pattern which can be stated as follows:

1. a statement of the problem in such a way that intelligent and answerable questions may be asked about the problem.
2. asking questions
3. making observations in the light of the questions that have been asked
4. reporting the observations made
5. revising tentative conclusions concerning the answers to the problem according to the reports received."

in a given OD is not available due to conflict in demand by another test, a combination of different equipments may be assembled and scheduled (a technical equivalent) permitting both tests to run simultaneously assuming the priority network and proximity of other tests permit.

This "if-and-but" matrix in which the scheduling process is imbedded epitomizes and justifies the term heuristic environment contained in the title and used throughout this dissertation. Enthusiasm and confidence stemming from the initial concept that the scheduling process could be modeled suffered violent fluctuations in the exploratory sessions described. A plan ultimately emerged to attempt to put in the form of algorithms the more obvious and traceable networks of factors making up otherwise heuristic judgments influencing scheduling, and, to make these algorithms part of the model. In those cases where the factors were transient or reserved for use by scheduling officers, the decision was made to have the scheduling model ignore them <u>but</u> to identify and print out apparent conflicts for final resolution by human schedulers.

Other factors, mentioned in passing, which may influence scheduling judgments and which, therefore, are part of the "shadow" priority system are:

1. The subjectively derived "probability" that a given test will be run as scheduled. Such "probability" is based on background knowledge of the scrub/run ratio and current circumstances

influencing the particular test under consideration. Prediction based on experience appears to be sound. A low probability implicitly assigned to actual arrival of a given test as scheduled may be used in the scheduling of other tests relating to it to minimize disruption of the over-all schedule in the event of its expected cancellation or early scrub.

2. The past performance of the range in supporting the test under consideration when previously scheduled, or, in relation to other prior tests in the series.

Factors for the above could be derived from appropriate records and included in the priorities algorithm and scheduling model. By making such subjective factors explicit, all concerned could play the game by the rules. In the event of disagreements, issue could be taken with the rules rather than individuals using them in spirit if not in fact.

In summary, the relationships of the Department of Defense, Armed Services and NASA as range users, and the Air Force Missile Test Center as the Department of Defense Executive Agency for the Atlantic Missile Range have been identified. The steps by which the Range is involved by programs from their inception to live test participation and delivery of test data have been traced. See Figure 9.

The process of random arrival of tests, probabilistic demand for test instrumentation, the complexity of the scheduling process and the character of heuristically based scheduling decisions have been adequately described. The necessity for eliminating a large number of combinations and permutations of equipments required versus available, the 95% rule, for reducing the proposed scheduling model to manageable proportions within restraints imposed on the research effort has been identified. It was conceived that the pilot model would be developed to manipulate test requests and produce a schedule for a typical week considering all practical elements and approximations of heuristic judgments employed; that, through evolutionary expansion and gaming for analysis purposes, the model would provide the answer to the question: What is the optimum man-machine combination for scheduling processes?

CHAPTER III

THE PROCEDURES FOR IDENTIFYING FACTORS IN THE SCHEDULER'S MIND THAT ARE THE BASIS FOR HEURISTICALLY DERIVED SCHEDULING DECISIONS AND IMPLICATIONS FOR OPERATIONS RESEARCHERS

An introduction to the existence and character of the heuristic environment in which range scheduling operates was made in Chapter II. The purpose of this chapter is:

1. To review experiences with schedulers in secluded sessions arranged to explore in detail the network of factors making up the heuristic environment in which scheduling is performed. The probing question quasi-psychiatric technique instrumentally employed will be emphasized.
2. To offer some generalized-to-specific observations and procedures useful to operations researchers who may be involved in modeling scheduling operations -- particularly those conducted in a heuristic environment.
3. To record some cursory remarks concerning the transition of operations researchers

from student to professional status.

A life long interest in psychology has been nurtured by considerable reading of popular and semi-technical literature on the subject, participation in management courses, and experiences in dealing with people in professional associations over the years. This background coupled with the experience reported in this dissertation is the basis for the observations and conclusions to follow.

It was discussed earlier that the author, because of the heuristic environment in which missile and spacecraft scheduling operates, found no way to analyze the scheduling problem from a peripheral vantage point but, of necessity, became an observer participant. This included listening in on many telephone conversations between schedulers and range users over an extended period -- an apparently trivial step which none-the-less was responsible for initially determining that scheduling was made up of three identifiable time phased parts: Forecasting, Weekly Scheduling, and Real-time Scheduling.

Observation of scheduling steps performed on the scheduling boards on which all test requests are initially assembled provided the first indication that a "shadow" priority system was at play. As was mentioned in Chapter II, when this proposition was presented to scheduling officers their initial reactions were that they were not aware of a priority system, as such, underlying their judgments; that they were not immediately able to outline its scope or origin. Finis to the research effort may have been written here since it was obvious that to gain full appreciation of the "shadow" priority system and the over-all scheduling process would require full-time participation in the scheduling operation for a period of approximately two years -- the period of on-the-job training estimated to be required to achieve full competence as a scheduling officer. It was not possible to secure sufficient concentration by scheduling officers to determine the character of the priority system because of continuous interruptions by jangling telephones and visitor scurryings which are normal features of the scheduling control environment.

Because of mutual interest in exploring the "priority" situation, it was agreed that scheduling officers in groups of two's could, at appropriate slack periods, be made available in a remote, closed room. The selection of an appropriate initial question as a gambit for exploring the source(s) of the priority system posed the first problem. Previously in this paper it was discussed that the DOD priority associated with test programs was, at times, violated; that the reason given was that a prelaunch support test for a low priority program assumed a higher priority if it were associated with an imminent launch. In preparation for the secluded session, the author noted and listed this and other seemingly contradictory scheduling decisions which appeared to be based on identical sets of circumstances. These were accumulated as propositions to be used in conducting the secluded session.

In the process of preparation it became obvious that if each contradictory scheduling decision or proposition on the list were discussed exhaustively, a session of great length or several sessions would be required. This did not allow for necessary excursions which would undoubtedly arise during the discussions. An estimate that many hours would be required was discussed with the Chief Scheduling Officer. It was agreed that as many afternoons as would be required in as rapid a sequence as possible would be arranged and the first such session was scheduled.

The opening proposition served its designed purpose but the subsequent trend of discussion bore little resemblance to the outline as conceived. Many productive and unproductive excursions occurred in the flow of discussion with only sporadic attempts made to return to the outline. When such attempts were made, it was noted that the spontaneity being enjoyed just prior to such regimen was immediately dispelled requiring considerable effort on the part of the researcher and participant to induce its re-establishment.

The productive excursions raised new sets of "if-and-but" conditional circumstances making up parts of the heuristic environment. It was necessary for the author to note these new conditional circumstances, concentrate on their detection in subsequent periods of observation, and develop related lists of questions for efficient exploration in follow-on secluded discussion sessions.

Frequently, the schedulers would introduce experiences and recall examples which were related to the Forecast and/or to the Real Time phase of scheduling -- not the Weekly Schedule isolated for the research effort. Often much was learned from these excursions. When such excursions were judged to be either non-contributory to the main research effort or to have reached diminishing returns, gentle efforts were made to steer the conversation back to the main propositions. On occasion, the scheduling officers themselves recognized the excursions and abruptly broke them off creating a temporary vacuum or loss of spontaneity as noted previously. The frequency of departures from the main issues diminished in time as awareness of the specific objectives, and means for isolating the factors having a bearing on them, evolved.

The provocative listing of propositions and questions, though not followed in order, was highly productive in over-all guidance of the discussion. Sometimes the natural flow of discussion concerning propositions or the injection of ideas would jump order. Having learned early not to stick to the script it, nevertheless, served as a check list which allowed all the preidentified propositions and questions to be covered. Intensive concentration by the author was required to catalogue the desired information arriving more or less at random in the flow of discussion while at the same time applying gentle control to avoid covering the same ground or making abrupt changes in subject matter.

Another important, perhaps the most important, observation resulting from the first secluded session, was that enthusiasm and spontaneity in the exploratory atmosphere enjoyed by researcher and participants was maintained at high level for approximately one and one-half hours. After that time the interest waned. Sensitivity to this reaction caused the researcher to call the session to a halt even though only a few of the propositions and questions on the list had been dealt with. Researcher and participating scheduling officers alike noted a feeling of uncommon mental fatigue and, yet, complete unawareness of the passage of such a significant bloc of time. No thought was given at this time to decreasing the frequency or reducing the length of sessions as previously planned.

The author found that the hours of effort required to recapitulate the information stored mentally and in cryptic notes resulting from responses to propositions and questions was much greater than that anticipated. Findings had to be collated and netted with the objective of structuring algorithms to approximate heuristically based factors underlying scheduling decisions. The recapitulation process was a vital link in the preparation of new propositions and questions for subsequent sessions and the recalling of old propositions in part to fill identified gaps.

The next follow-on session, two days after the first, was "flat" -- failed to achieve either spontaneity or to produce much usable information. A hypothesis was formed as a result of retrospection on these contrasting results: Failure of the second secluded session relative to success of the first could be correlated with the short time interval between sessions and some output/recovery cycle having a psychological origin.

The time separation between subsequent sessions was increased. A return to the productivity of the original session was noted. Because the separation between secluded sessions was in part dictated by the match of time available on the part of the researcher and participants, this experiment in timing sessions and measuring productivity cannot be classed as either a designed or controlled experiment. Results of these experiences, however, were provocative and were considered of sufficient importance for inclusion in this dissertation. The author has not been able to find references in the literature which deal with the spacing of discussion sessions or their length and bearing on the psychological reactions of researcher and participant engaged in "brain storming" session of this type.

It is the conclusion of the author that maximum productivity of secluded sessions was attained when the sessions were separated by a minimum of one and not more than two weeks and the time per session did not exceed two hours. Further, it is concluded that maximum responsiveness and productivity was achieved when one researcher and two scheduling officers were involved. Combinations of 1 to 1, 1 to 2, and 1 to 3, were tried.

The implications of the above for other operations researchers involved in similar endeavors are that, first, proper appreciation of the psychological response of one human being to another is a vital consideration in progress from problem formulation to ultimate solution and, second, rate of achievement may be sensitive to some mental output/restoration cycle which cannot be violated without discouraging results or ultimate failure. This latter suggests an axiom: If one man can do a job in three months, thirty men cannot necessarily be expected to accomplish the job in three days -- particularly where human psychology may be a significant factor. Systems Analysis by large teams of operations researchers intending to make short work of a major problem may find that the psychological response of individuals or groups involved may play a significant role in both efficiency and success of the endeavor.

Some generalized-to-specific observations and recommendations concerning modeling of scheduling operations can now be assembled. These will range from comments concerning scheduling models studied during search of the literature to the modeling of the scheduling operation in a heuristic environment just described. Emphasis will be devoted to the latter.

In the broadest sense, all managers of organizational elements are schedulers of men, money and/or material. The success of this nation in progressing from an agricultural to an industrial economy can be attributed to a penchant for visualizing human wants and ingenuity in simultaneously achieving rationalization, specialization and coordination in the scheduling of resources from raw materials to finished products. Whether the output of an organization is a physical product or a service, the tendency has been to depend on human schedulers and their rational subjective decisions until the operation became so complex that the capacity of the scheduler to handle the job was threatened or some objective was believed to be compromised. From Frederick Taylor to the present, it is at this point that Operations Research modeling can and has demonstrated its most remarkable influence and payoff.

Many scheduling situations involving products or services have characteristics in common. A number of classical models, or adaptations, can be employed manually or through use of computers to optimize scheduling processes to satisfy given objective functions. Such models assume that the product is uniform and the parametric values are specifically known or follow some identifiable distribution. However, the particular scheduling problem facing an operations researcher may not fulfill these requirements. Consider a scheduling function having the following features:

1. Schedules resources and/or services of high economic or national significance.
2. Has reached (or will reach) the saturation point of human capacity, or, is suspect from the standpoint of satisfying some objective criteria, and
3. Has previously been considered analytically unassailable because of its operation in a heuristic environment where human reasoning and negotation are involved.

Under such circumstances, the application of classical models, or even their extensions, offer little promise of success unless extensive surgery to modify the scheduling operation to fit the model is conceivable and in order. When such a scheduling operation is encountered and management voices concern about its future capacity or efficiency and elects to use Operations Research to effect a solution, the researcher is in line for a most interesting and challenging experience. The research described in this dissertation had such a setting.

It is important to review some of the potential "people" situations which must be appreciated if modeling of scheduling operations performed in a heuristic environment is to be given every opportunity for success. The first thing to recognize is that the scheduler of acts or resources of great economic or other significance occupies a highly strategic position. He is invariably a man of proven unusual talent, mental capacity, emotional durability, and dedication. His intimate knowledge of all the ramifications of a complex scheduling job is responsible for its successful achievement usually measured by subjective standards. There rarely, if ever, is a rule book or guide in sufficient detail to describe his decision-making processes. Besides official publications, the reference sources he uses may involve charts, tabulations, or other devices of his own invention which may or may not be orderly or replete to the uninitiated. They usually provide "key" information to him which, integrated mentally, gives him the basis for scheduling decisions. He is a man of self-esteem, may entertain feelings of indispensability, has considerable vested interest in his successful accomplishments, and may or may not exhibit symptoms of self-protection against an outsider (the researcher) attempting to enter his domain.

The first impression may be a lasting one. The researcher's initial contact with the scheduler is all important in setting the stage for the degree of success which his research effort will achieve. Before direct involvement with the scheduler, the researcher should become familiar with the services or resources sought by customers. He should have some knowledge of the satisfactions resulting from the heuristically executed scheduling decisions. This preparation will obviously provide a basis for discussion and generate interest in the involvement of the researcher. Also, the researcher may, before the fact or early in his involvement, discover product flow points above, below, or within the scheduling function which yield to measurement and data collection sufficient for modeling and analysis of the scheduling operation. This was the case as reported in the OR study, Traffic Delay at Toll Booths.[1] Edie remarks only casually that toll sergeants responsible for scheduling toll collectors were interviewed by operations researchers involved. If the data essential to the study can be collected by external observation without dependence on information available only from the principals involved, so much the better. This is not a very likely circumstance if the scheduling operation is imbedded in a heuristic environment and services are the primary product.

In other cases where the product flow into and out of the scheduling function are intangible or dispersed, such as requests for service and subsequent allocations, there may be no obvious or reliable "pulse" points to determine input/output qualitatively and quantitatively. In such a case, involvement of the researcher as a participant and

[1]Leslie C. Edie, Journal of the Operations Research Society of America, 2, No. 2, 107-138 (May, 1954).

observer on the job becomes a necessity. Such a circumstance puts a premium on compatibility with the principals involved at the outset.

The researcher must make every effort to be accepted as "one of the team." He must be especially sensitive to the sincerity and quality of the cooperation he receives as he gathers experience and isolates meaningful data collection points. Schedulers may be fully cooperative in skillfully exposing the researcher to the key elements in the scheduling function and answer all questions fully, or they may be uncooperative by various means rationalized by the necessity for maintaining their prerogatives. Only the researcher can tell and must adapt his observation techniques accordingly. No amount of authority exercised from above will accomplish results which the researcher can achieve by his own deportment -- and authority should be avoided until all other means have failed.

Once the researcher gets a "feel" for the scheduling function from participation, he should begin to identify and classify scheduling decisions observed into two broad categories: Those which are predictable and occur repetitively based on identical sets of circumstances which appear from time-to-time and those which appear to be contradictory when apparently identical sets of circumstances occur. This latter list is the basis for the quasi-psychiatric technique for extracting from the scheduler's mind the factual basis for heuristic judgments.

Having assembled such a list of seemingly contradictory scheduling decisions, or propositions, the researcher should arrange a special discussion session with the scheduler remote from the work place and under secluded conditions to minimize distractions. He should then begin his review of "contradictions" and propositions identifying apparently identical circumstances under which they were made. The obvious objective is to have the scheduler identify the factor(s) or consideration(s) which modified the apparently identical set of circumstances and resulted in contradictory scheduling decision(s).

By proceeding down the list of contradictions and propositions, the major and minor elements underlying heuristically based decisions can be identified. The explanations of contradictions, in themselves, will be the basis for identifying other seeming contradictions. This process will also sharpen the researcher's sensitivity of observation during subsequent on-the-job participation. This serial process of observation and participation, secluded discussion sessions, and post-discussion recapitulation and analysis can be very effective in accelerating the identification of the network of factors underlying the scheduler's decisions. The interesting fact is that gross-to-incidental influences affecting scheduling decisions will come from the decision maker's mind as a result of this iterative quasi-psychiatric technique which he would not be able to identify or list if asked to do so directly.

The next steps are to arrange and select the major and repetitive factors identified which exercise the predominant influences on scheduling decisions and to make the first attempt to put them in the form of a logic flow diagram. In a subsequent conference with the scheduler, the logic flow diagram should be presented for his response as to whether it more-or-less approximates his heuristic judgment process for arriving at scheduling decisions. This puts the scheduler in the position of having either to accept the researchers translation of his decision making processes or to identify necessary changes in the flow network. Either of these results is equally satisfactory.

When the propositions-and-logic-flow-diagram-discussion-routine reaches a point of stability, or of diminishing returns, the next step in the process may be initiated. The logic flow diagrams can be converted to a set of rules of engagement for clarifying and simplifying the scheduling function. (This stage will represent a significant level of achievement in its own right because "customers" aware of the rules may argue with the "system" in the event of disagreement with scheduling decisions instead of making the decision maker their target.)

A follow-on step, depending on the scope of the problem, is to develop a computer program for the scheduling operation, in whole or in part, including the algorithm of factors previously imbedded in the heuristic environment.

Such a model and computer program will provide the best base possible for cost/effectiveness analysis to support decisions concerning the optimum man-machine combination.

General guidelines may now be summarized in the form of questions and answers to aid an operations researcher in bracketing the type of scheduling operation with which he is to be involved and the method for tackling the modeling problem.

1. Does the scheduling function to be studied control resources or services of sufficiently high cost or other significance to justify the cost of making an analysis, modeling the function, and introducing computer aids? If so, the analysis is worth the effort.
2. Does it involve the category of production line or job shop scheduling -- a physical end product? If it does, many models already developed, or their adaption, may solve the problem. Consult the bibliography and other appropriate references.
3. Does it fit into the category of scheduling services or acts for which rules of engagement exist or may be straightforwardly identified? Similarly, many existing models or their adaptions may apply.
4. Does it fit into the category of service and/ or resource scheduling to meet custom demands

in a heuristic environment? If so, existing models or their extensions are inadequate.

Knowing that the operation to be analyzed depends on human schedulers employing heuristic judgment and is of sufficient economic or other consequence to warrant modeling, the operations researcher can employ the following steps:

1. Look for check points in the system at which data concerning services or resources offered and schedule results may be collected by impersonal means outside or within the scheduling operation. If such check points exist, data collection and analysis may proceed without necessity for direct participation of the researcher in the scheduling function and/or dependence on interview of principals involved. If check points adequate to the purpose do not exist, resorting to participation and discussion sessions to accumulate data for modeling purposes will be necessary.
2. Study the operation which the scheduling function services and develop familiarity with the acts or resources sought by customers and acquire some knowledge of satisfactions resulting from the heuristically executed scheduling process.
3. Develop a logical plan for being "invited" to

observe and participate in the scheduling process with emphasis on becoming an accepted member of the scheduling team.

4. Observe and follow the pattern of scheduling decisions with particular attention to those which seemingly are inconsistent involving apparently identical circumstances. Assemble such seeming contradictions over a respectable period and arrange a secluded discussion session with the scheduler(s) so that he can supply the qualifying education. Try to induce the "Hawthorne effect."[2]

5. Continue the participation, discussion, and recapitulation procedure until sufficient background is accumulated to attempt an initial logic flow diagram of the scheduling process. Submit this to the scheduler(s) for evaluation, criticism, correction, and evolutionary development backed by increasingly effective observation until the model approximates the scheduling process.

6. Employ the logic flow model (algorithm) to identify areas where increased scheduling discipline can be imposed with little loss in effectiveness.

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[2]Improvement of an operation induced by interest of the participating subjects somewhat independent of experimental conditions varied.

7. Program the algorithm(s) for computer assistance to the scheduling function.
8. Continue evolutionary development of the computer model. Such a model can provide an inherently effective base for continuous cost/effectiveness analysis of the degree of automation which should ultimately be embraced.

It seems appropriate to include some cursory remarks concerning the transition of operations researchers from student to professional status. The exposure of students in problem oriented Operations Research, Mathematics, Statistics, etc., courses almost invariably is accompanied by data inputs being "given". The problems presented are usually "sanforized" to avoid complexities in the interest of concentrating the exposure of students to principles or techniques.

The professional world in which the former student must exercise his training requires three major adjustments which are difficult to teach but must be learned. First, he must have the imagination to correlate academic problems with real world problems. Second, he must develop his own models through identifying and extracting meaningful inputs from people of widely varying capabilities for appreciating the objectives and the means. (Such input data is rarely as "clean" as that to which he was exposed in the academic scene.) Third, he must perform these model developments and secure their implementation through people at all levels whose attitudes may vary from open hostility, through passiveness, to uninhibited cooperation.

The more complex the problem, in general, the greater will be the range of challenge in the three aspects described above and the more important will be the skillful adaption of the operations researcher to the "people" equation if success in his endeavors is to be achieved. Since the operations researcher is a human being himself he must maintain a degree of self-disciplined detachment from emotional fluctuations of discouragement and enthusiasm which are bound to arise in transporting his objectives over the rocky route from conception to achievement.

In summary, the necessity for actual involvement by the author in Range Scheduling operations rather than observation and/or collection of data at a peripheral vantage point was reviewed. The need for special discussion sessions with schedulers to explore in detail the network of factors making up the heuristic environment in which they operate was identified. The recording and use of apparently contradictory scheduling decisions, separated in time, as a device for inducing schedulers to identify causes and, therefore, heuristic factors at play, was emphasized. The role of scheduling in our society and generalized procedures for extracting data from schedulers operating in a heuristic environment were discussed. Finally, a cursory review of the problems which operations research students may encounter in transition from academic to professional status was presented.

CHAPTER IV

DEVELOPMENT OF THE IMPLICIT PRIORITY SYSTEM, ALGORITHMS, AND A COMPUTER PROGRAM TO APPROXIMATE HUMAN SCHEDULING DECISIONS

Up to this point the complex scheduling process and the use of heuristically derived judgments have been identified. The relationship of these judgments, the "shadow" priority system which underlies their qualitative character, and the research techniques used in secluded sessions to identify the fundamental factors involved have been established. It now remains to identify those factors selected, assemble them in the form of an algorithm(s), express the algorithm in machine language, and develop an over-all scheduling model and computer program containing them.

It was initially revealed in the secluded sessions that major launch tests as a category take precedence over all "other" tests and generally require commitment of nearly all major range instrumentation systems. The "other" tests for the moment are identified as support tests. Also revealed was the fact that a number of the support tests do not require the commitment of <u>common</u>

range resources and may be scheduled at times requested without interference even though test times are congruent or overlap. These two categories of tests were conceived as occupying the highest and the lowest priority rating, respectively, on a scale along which the remainder of the supports tests, properly categorized and ordered by priority, could be placed. This supposition was validated and a priority category system was developed letter A through H as follows:

A. Major launch tests.

B. Associated Tests. A category of tests run for purposes of research of phenomena, equipment calibration, or measurement. By definition and arrangement they are run concurrently with launch tests on a no-conflict basis.

C. Down Range Support Tests. A category of tests involving down range stations only. Under the 95% rule they are considered as non-conflict tests and may be scheduled at times requested if they do not interfere with major launches.

D. F-1 Day Tests. A category of support tests run one week, prerequisite to a major launch forecast for the following week.

E. F-6 Day Tests. A category of support tests run one week, prerequisite to a launch forecast for the second week removed.

F. F-X Day Tests. A category of support tests run one week prerequisite to a launch forecast for a future week more than two weeks removed.

G. Support Test Other. A category for AMR or other agency development tests not connected with a particular launch or program involving launches. They may be assigned relative priorities.

H. Non-interference Support Tests.

It developed that within the major launch tests, Category A, if two tests were requested with conflicting T-times, the DOD priority may or may not suffice to give precedence of one test over the other. For instance they may be of the same priority. In one instance in which this happened there was little hesitation on the part of the scheduling officer as to which test would be given the anchor position on the schedule and which would be tentatively slipped or advanced out of the conflict time zone. The underlying reason was that one of the tests had an "hours launch window." Translated, this meant that the anchor test had a T-0 time ± 15 minutes so that upon re-entry of the nose cone at T + 20, some miles down range, phenomena could most favorably be recorded by photographic means. Outside this re-entry time window the opportunity for observation and recording would be subject to rapid deterioration. It was subsequently determined that there are launches which have "day launch windows." Here a span of days are involved during which the launch can successfully attain some objective relative to celestial mechanics with deterioration on both ends of the "day window" spectrum. Many classified test objectives generate the requirement for hour and/or day launch windows. Therefore, combinations of the time period in which a future launch is to occur, its DOD priority and the existence of a days or hours launch window can be used to establish schedule priorities.

For example, a launch which is to occur in the following week, has a DOD priority "1", has a days launch window ≤ 3 days, and an hours launch window ≤ 3 hours may be assigned a scheduling priority of "1" because of its inherent DOD published priority and its lack of tolerance for manipulation of its requested T-0 time. Similar reasoning would assign a scheduling priority of "3" to a launch which is to occur the following week, has a DOD priority of "1", has a days launch window but does not have an hours launch window. In this case the launch has complete tolerance for shifting to other T-times on any requested day if it is in conflict with a launch of higher priority without such tolerance for slippage. Similar reasoning would assign a scheduling priority of "2" to a launch to occur the following week, having a DOD priority "2", and having both days and hours launch windows. The scheduling priority algorithm, for launches, Figure 10, was developed to yield scheduling priorities 1 through 8 corresponding to the combinations of DOD priorities "1" and "2", days launch

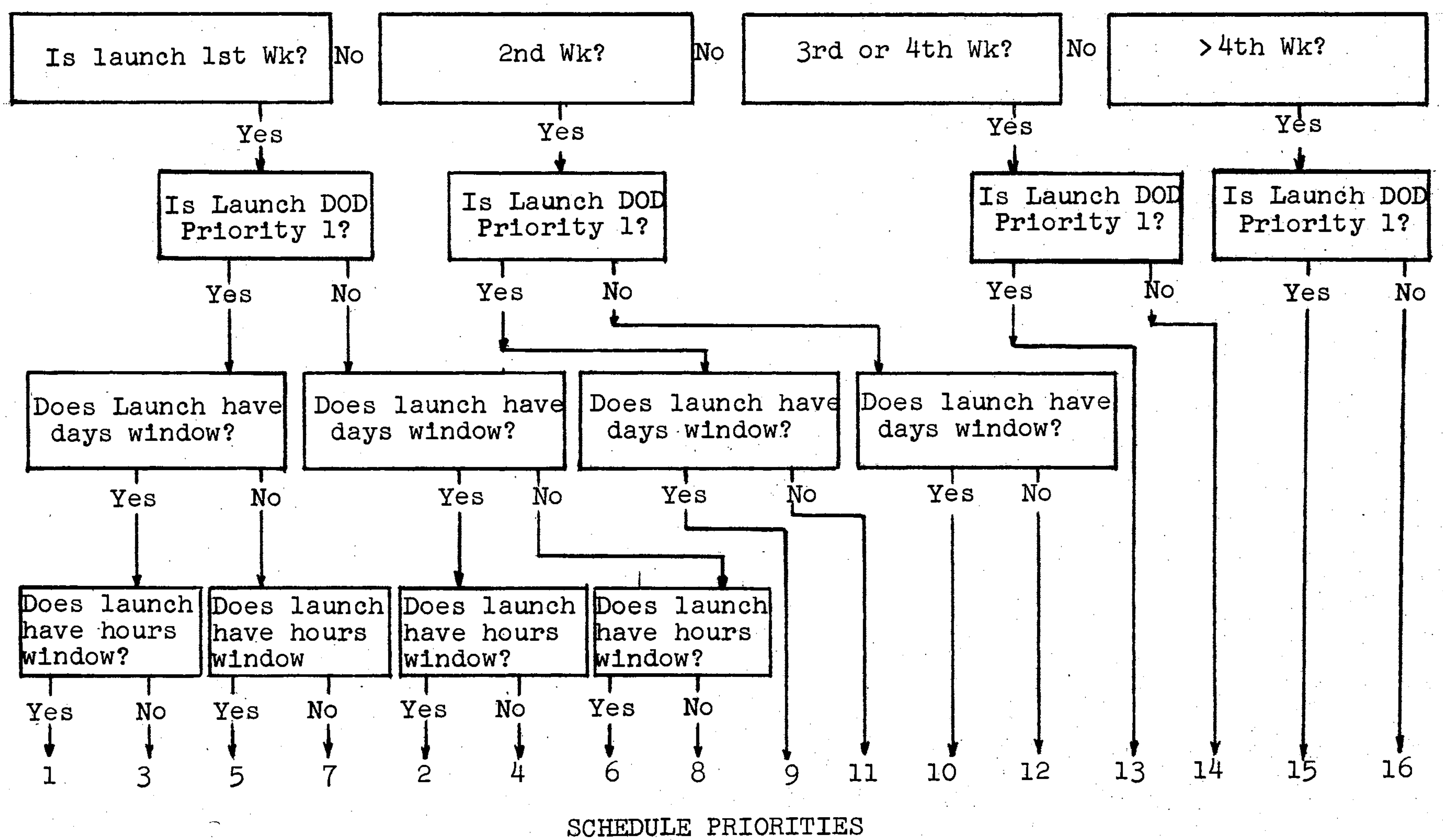

Figure 10. The Scheduling Priority Algorithm

windows "yes" or "no" $\leq$ 3 days, and hours launch windows "yes" or "no" $\leq$ 3 hours.

Considering that the F-1, Category D, support tests are prerequisite to a major launch, they can be assigned the same priority as the major launch which they are to precede. Analogously, the F-5, Category E, and F-X category F support tests can be assigned a priority consistent with the launch and the future period in which the launch is forecast to occur. The algorithm was extended for this purpose. The extension of the scheduling priorities algorithm to include priorities 9 through 16 reflects the decreasing influence of the future time period and the hours and days launch windows respectively on the assignment of priorities.

Thus, the composite algorithm of categorization of tests in the order of their importance and the ordering of scheduling priorities of tests within the categories approximates the "shadow" priority system applied by the human scheduler. A machine program for this scheduling priority algorithm has been prepared but is not included in this dissertation. It has not been included in the computer scheduling model to avoid a demonstration which would involve the use of launch forecast information and which could violate security restrictions. Also considering at this early stage the optimum man-machine combination, the categorization of tests and the assignment of priorities within categories has been reserved as a function of scheduling officers for insertion in a tabular form used to prepare tests requests cards (tape) as the basic input to the computer scheduling model.

There are many factors influencing scheduling priorities which have not been included in the priority algorithm. These excluded factors are for the most part associated with special or rarely repetitive circumstances. An example is the assignment of precedence to a test it would not otherwise enjoy because of the expected presence of an important visitor interested in a particular program. Another example is the assignment of an overriding precedence to a launch which is the subject of national popular interest, possesses extensive news value, or is significant for its expected influence on national prestige. In such cases, the algorithm can be employed to select an outsized priority for a test which will assure it priority attention by the machine scheduling program.

The Scheduling Request Working Form designed to supply all necessary test request and supporting data for machine scheduling of a typical week is shown in Figure 11. These data were transferred to punch cards (tape) by standard processes as the basic input to the 1620 computer scheduling program. The scheduling model, the description of which is to follow, will be exercised to test its ability to reproduce a weeks schedule for comparison with the schedule prepared and published by scheduling officers.

Before presenting the scheduling model in its final

Day	Date	Test No.	O.D. No.	Range Equip. Req'd?	Test Short Title	Test Category	With Test No.	₹3 Hour Launch Window	₹3 Days Launch Window	Test Priority	S- (Start) Time	T- (Test) Time	E- (End) Time	Limit Code	O.D. Changes Written	O.D. Changes Coded	Remarks
Mon.	09/12	8232	07470	No	Tranet Readout	C	-	-	-	-	0000	0100	0200	-	-	-	-
"	"	8233	07470	No	Tranet Readout	C	-	-	-	-	1400	1500	1600	-	-	-	-
"	"	8452	MS	No	Gemini	H	-	-	-	-	0001	-	2359	-	-	-	WB pairs looped sim lengths. No O/T auth.
"	"	8453	061H	No	Riometer Absorp.	H	-	-	-	-	0001	-	2359	-	-	-	-
"	"	8454	066B	No	STC CAT II Ops.	G	-	-	-	-	0001	-	2359	-	-	-	Tri 40 Hrs. BOM Disc. Delete Sta. 91
"	"	8455	097	Yes	Bridge Gap	G+	-	-	-	12	0930	-	1130	Delete	All support except optics	2/3/4/5	Optics sites 1.5,3.5,4.1,5.1,. Timing. ARCPE follows
"	"	8456	MS	No	Gemini	H	-	-	-	-	1130	-	0345	-	-	-	Seq. Op. to BH O/T Authorized
"	"	8457	093C	No	GMCF #1 Boresight	H	-	-	-	-	1200	-	-	-	-	-	-
"	"	8458	1131E	No	Titan Gnd. Inst.	H	-	-	-	-	1200	-	-	-	-	-	Pad__, 1 shift Pad__, 2 shifts
"	"	8459	069	No	Tropo Refract.	H	-	-	-	-	1300	-	1500	-	-	-	-
"	"	8460	095A	No	SAC RBS	C	-	-	-	-	1345	-	1715	-	-	-	-
"	"	8461	069A	No	Tropo Refract.	G	-	-	-	-	-	1630	-	-	-	-	C-131 Acft only, T/O PAFB T-150 Flt. plan F, Phase II
"	"	8462	005B	Yes	Loki II Launch	G	-	-	-	-	1600	1600	1635	-	-	-	Pad __
"	"	8463	1105B	Yes	Titan IX	D	3787	Yes	No	5	1635	1700	1715	-	-	-	Pad __ Msl N-29
"	"	8464	1131A	Yes	Titan Sim. Flt.	D	-8463	Yes	No	5	1635	1700	1715	-	-	-	W/8463
"	"	8465	166	Yes	MDS	D-	-8463	Yes	No	5	1635	1700	1715	Delete	Tel 2	2 a	W/8463
"	"	8466	068A	Yes	CARDE A/B	G	-	-	-	-	1630	1700	1830	Delete	All support except timing	3/5	CF-100 Stage PAFB
"	"	8467	095B	No	SAC RBS	H	-	-	-	-	1745	-	2100	-	-	-	-
"	"	8468	098E	Yes	Baloon Track	G	-	-	-	-	1930	1930	2030	-	-	-	-
"	"	8469	098D	Yes	Nike Smoke Rocket	G	-	-	-	-	1930	1930	1933	Delete	Pre Cal-Post Cal	2"a"/2"b"	Pad __ Lch Az. 060
"	"	8470	098A	No	Wind Data	G	-8469	-	-	-	-	1930	-	-	-	-	W/8469
"	"	8471	097	Yes	Bridge Gap	G+	-	-	-	-	2230	-	0030	Delete	All support except optics	2/3/4/5	Optics sites 1.5,3.5,4.1,5.1,. Timing. ARCPE follows
Tues.	10/12	8472	093F	Yes	G/E Airborne	G	-	-	-	-	2231	0001	0401	-	-	-	C-131 #803. FH plans G & Q2. T/O T-60
"	"	8234	07470	No	Tranet Readout	C	-	-	-	-	-	0100	-	-	-	-	-
"	"	8235	07470	No	Tranet Readout	C	-	-	-	-	-	1500	-	-	-	-	-
"	"	8473	1131E	No	Titan Gnd. Inst.	H	-	-	-	-	1200	-	-	-	-	-	Pad __ 1 shift, pad __ 2 shifts Delete Seq. & timing
"	"	8453	061H	No	Riometer Absorp.	H	-	-	-	-	0001	-	2359	-	-	-	See Monday
"	"	8454	066B	No	STC CAT II Ops.	G	-	-	-	-	0001	-	2359	-	-	-	See Monday
"	"	8456	MS	No	Gemini	H	-	-	-	-	-	1200	-	-	-	-	See Monday
"	"	8459	069	No	Tropo Refract.	H	-	-	-	-	1300	-	1500	-	-	-	See Monday
"	"	8474	093C	No	GMCF #1 Boresight	H	-	-	-	-	1200	-	-	-	-	-	
"	"	8475	2532	Yes	Delta Acceptance	E	5332	Yes	Yes	9	1300	-	1700	-	-	-	No 22, Pad __, SC Rad clnc. on 136.23/.92/.95,235.0,_ (C)

Figure 11. Scheduling Request Working Form Containing all Necessary Test Request and Supporting Data for Machine Scheduling of a Typical Week

Tues. (cont'd)	10/12	8476	095A	No	SAC RBS	C	-	-	-	-	1345	-	1715	-	-	-	-
"	"	8477	061G	No	ATL Duct	C	-	-	-	-	-	1400	-	-	-	-	Tri radar 2 Hrs.
"	"	8478	1230	No	Atlas tanking	F	575	Yes	No	15	1500	-	-	-	-		Msl 137F, Pad __,A/F Tlm Rad.
"	"	8260	203A	Yes	Polaris Dry Run	D	6666	No	No	7	1450	1650	1740	Delete	TLM 248.6,2531 C-BCN. & AMR Comd.	2w/2a/4	Msl 46, Dock only, MOPS 12, Delete Comm nets, & Azuza R/O's
"	"	8480	098E	Yes	Baloon track	G	-	-	-	-	1930	1930	2030	-	-	-	-
"	"	8481	1131C	No	Titan tanking	B	3787	Yes	No	5	2400	-	-	-	-	-	Pad __, Msl N-29
"	"	8482	1131D	No	Titan tanking	B	3787	Yes	No	5	2400	-	-	-	-	-	Pad __, Msl N-29
"	"	8479	095B	No	SAC RBS	C	-	-	-	-	1730	-	2045	-	-	-	-
Wed.	11/12	8483	093F	Yes	GE Airborne	G	-	-	-	-	2331	0001	0401	-	-	-	C-131 #803. Flt plans G & Q2
"	"	8236	07470	No	Tranet Readout	C	-	-	-	-	-	0100	-	-	-	-	-
"	"	8237	07470	No	Tranet Readout	C	-	-	-	-	-	1500	-	-	-	-	-
"	"	8484	097	Yes	Bridge Gap	G+	-	-	-	-	0930	-	1130	Delete	All Support Except Optics	2/3/4/5	Optics sites 1.5,3.5,4.1,5.1,. Timing. ARCPE follows
"	"	8485	093C	No	GMCF #1 Boresight	H	-	-	-	-	1200	-	-	-	-	-	-
"	"	8486	1131E	No	Titan Gnd. Inst.	H	-	-	-	-	1200	-	-	-	-	-	Pad __ 1 shift, Pad __ 2 shifts Delete Seq. & timing.
"	"	8487	068A	Yes	CARDE A/B	G	-	-	-	-	1130	1200	1330	Delete	All Except Mod II and timing	5	CF-100 PAFB Sta. 1 Mod II Radar
"	"	8271	203A	Yes	Polaris Dry Run	D	6666	No	No	7	1300	-	1500	Delete	TLM 248.6,253.1 & AMR Command	2.W/2.a1/1	R/O's TLM, Azusa, C-BCN. MOPS & TLM Same OD 203
"	"	8453	061H	No	Riometer Absorp.	H	-	-	-	-	0001	-	2359	-	-	-	See Mon.
"	"	8454	066B	No	STC CAT II Ops.	G	-	-	-	-	0001	-	2359	-	-	-	See Mon.
"	"	8456	MS	No	Gemini	H	-	-	-	-	-	1200	-	-	-	-	See Mon.
"	"	8459	069	No	Tropo Refract.	H	-	-	-	-	1300	-	1500	-	-	-	See Mon.
"	"	8488	095A	No	SAC RBS	C	-	-	-	-	1345	-	1715	-	-	-	-
"	"	8489	098E	Yes	Baloon Track	G	-	-	-	-	1400	1400	1500	-	-	-	-
"	"	8274	232H	No	Startracker Calib.	D	6666	No	No	7	1510	-	-	-	-	-	W/6666 or T-590/6666 until EAG undway. Delete Comd.
"	"	8490	069A	No	Tropo Refract.	G	-	-	-	-	1630	-	1830	-	-	-	C-131 Acft only T/O PAFB T-150 Flt. Plan F. Phase II
"	"	8491	2430D	Yes	Network Op. Readiness	F	6780	Yes	No	6	1200	1700	2100	-	-	-	Msl SA-5
"	"	8276	232G	No	Lorac Cruise	B	6666	No	No	7	1710	-	-	-	-	-	Lorac A Stable T-470/6666 until EAG Ports 12/1300E
"	"	8492	095B	No	SAC RBS	C	-	-	-	-	1745	-	2100	-	-	-	-
"	"	8493	098D	Yes	Nike Smoke Rocket	G	-	-	-	-	1930	1930	1933	Delete	Pre Cal, Post Cal	2"a"/2"b"	Pad __
"	"	8494	098A	No	Wind Data	G	-	-	-	-	-	1930	-	-	-	-	W/8493
"	"	3787	1105-8	Yes	Titan II Launch	A	3787	Yes	No	5	1650	2000	2100	-	-	-	Msl N-29, Pad __ Lch Az 85 Flt Az 106.60'BIH etc. Brief No. 56 Sites ___ etc.
"	"	8495	008	No	DRO Spec. Test	B	3787	-	-	-	-	2000	-	-	-	-	
"	"	8496	009	No	A/B Rad Mon.	B	3787	-	-	-	-	2000	-	-	-	-	C-131 Actf T/O PAFB T-60
"	"	8497	051	No	Flying Dutchman	B	3787	-	-	-	-	2000	-	-	-	-	C-131 Acft Stage PAFB Sta. 1 Mod II Rdr.
"	"	8011	060B	No	SPP	B	3787	-	-	-	-	2000	-	-	-	-	-
	"	8498	061ABC	No	OAR SDT	B	3787	-	-	-	-	2000	-	-	-	-	-
		8499	068	No	CARDE A/B	B	3787	-	-	-	-	2000	-	-	-	-	CF-100 Stage Sta. 1 Flt plan 1-160-40. Mod II

Figure 11. (Continued)

Wed. (cont'd)	11/12	8500	073W/A	No	Nike Zeus	B	3787	-	-	-	-	2000	-	-	-	-	Sta. 12 Code 10 EC-121 Acft
"	"	8501	080C	No	Navy GED	B	3787	-	-	-	-	2000	-	-	-	-	-
"	"	8502	084	No	RAMP	B	3787	-	-	-	-	2000	-	-	-	-	KC-135 Acft F/P 1-195-40 Optics V&M, Sta 1 Mod II
"	"	8503	162	No	DC-6 Rad	B	3787	-	-	-	-	2000	-	-	-	-	DC-6 stage ASC
"	"	8504	166	No	MDS	B	3787	-	-	-	-	2000	-	-	-	-	-
"	"	8505	177	No	Army Acoustic	B	3787	-	-	-	-	2000	-	-	-	-	-
"	"	8506	179	No	Army Backscatter	B	3787	-	-	-	-	2000	-	-	-	-	-
"	"	8507	181	No	RFDT	B	3787	-	-	-	-	2000	-	-	-	-	-
"	"	8508	185	No	LRFDT	B	3787	-	-	-	-	2000	-	-	-	-	-
"	"	8509	005D	No	Arcas Robin Launch	B	3787	-	-	-	-	2000	-	-	-	-	Or T+120 Pad __
"	"	8510	005G	No	Arcas Robin Launch	B	3787	-	-	-	-	2000	-	-	-	-	Or T+180 Sta. 12
Thurs.	12/12	6666	203-3	Yes	Polaris ___ Launch	A	6666	No	No	7	2210	0100	0200	-	-	-	Msl __46, Flt Az 115 EAG Underway T-410 etc.
"	"	8074	009	No	A/B Rad. Mon.	B	6666	-	-	-	-	0100	-	-	-	-	C-131 Acft Stdby PAFB T-60 Wx obs w/comm to CC Wx con
"	"	8520	020	No	A/B Tlm. Ant. Ckout.	B	6666	-	-	-	-	0100	-	-	-	-	C-130 Acft #628 Stage ASC Phase III
"	"	8076	051	No	Flying Dutchman	B	6666	-	-	-	-	0100	-	-	-	-	-
"	"	8077	061ABC	No	AFGED	B	6666	-	-	-	-	0100	-	-	-	-	-
"	"	8078	080C	No	Navy GED	B	6666	-	-	-	-	0100	-	-	-	-	-
"	"	8079	084	No	RAMP	B	6666	-	-	-	-	0100	-	-	-	-	KC-135 Stage WPAFB F/P 1-040-32 Optics V/M. Sta 1 Mod II
"	"	8080	163	No	GOST	B	6666	-	-	-	-	0100	-	-	-	-	Sta. 1 only. Delete all support except green phones--etc.
"	"	8081	170W/A	No	AREX. Opns.	B	6666	-	-	-	-	0100	-	-	-	-	-
"	"	8082	177	No	Army Acoustic	B	6666	-	-	-	-	0100	-	-	-	-	-
"	"	8084	179	No	Army Backscatter	B	6666	-	-	-	-	0100	-	-	-	-	-
"	"	8083	181	No	RFDT	B	6666	-	-	-	-	0100	-	-	-	-	-
"	"	8085	185	No	LRFDT	B	6666	-	-	-	-	0100	-	-	-	-	-
"	"	8086	240	No	PX Inst. Support	B	6666	-	-	-	-	0100	-	-	-	-	Phase II
"	"	9325	ITD031	No	Glotrac Tracking	B	6666	-	-	-	-	0100	-	-	-	-	Sta 1,5,7,91 BDA,ATL.
"	"	8521	093F	Yes	GE Airborne	G	-	-	-	-	2231	0001	0401	-	-	-	C-131 #803, F/P G&Q2
"	"	8238	07470	No	Tranet R/O	C	-	-	-	-	-	0001	-	-	-	-	-
"	"	8239	07470	No	Tranet R/O	C	-	-	-	-	-	1500	-	-	-	-	-
"	"	8511	093C	No	GMCF #1 Boresight	H	-	-	-	-	1200	-	-	-	-	-	-
"	"	8512	1131E	No	Titan Gnd. Inst.	H	-	-	-	-	1200	-	-	-	-	-	Pad __ 1 shift, Pad __ 2 shifts delete Seq. & Timing
"	"	8515	2400A	Yes	Saturn Dry Run	D	6780	Yes	No	6	1600	1730	2000	-	-	-	Msl SA-5, Pad __, OLC all RF fm T-90 to T+150
"	"	8513	095B	No	SAC RBS	C	-	-	-	-	1345	-	1715	-	-	-	-
"	"	8516	095B	No	SAC RBS	C	-	-	-	-	1745	-	2100	-	-	-	-
"	"	8514	061G	No	Atl. Duct	C	-	-	-	-	1300	1400	1500	-	-	-	Tri Rdr 2 Hrs
"	"	8517	2533	Yes	Delta All Systems	E	5332	Yes	Yes	9	1800	-	2000	-	-	-	No. 22, Pad __, S/C rad clnc 136.23/.92/.95,235.0,__(C)

Figure 11. (Continued)

Thurs. (cont'd)	12/12	8518	098E	Yes	Baloon track	G	-	-	-	-	1930	1930	2030	-	-	-	0.18 & Mod II
"	"	8519	068A	Yes	CARDE A/B	G	-	-	-	-	1900	1930	2100	Delete	All support except timing	3/5	CF-100 Acft PAFB
"	"	8453	061H	No	Riometer Absorp.	H	-	-	-	-	0001	-	2359	-	-	-	See Monday
"	"	8454	066B	No	STC CAT II Ops	G	-	-	-	-	0001	-	2359	-	-	-	See Monday
"	"	8456	MS	No	Gemini	H	-	-	-	-	1130	-	0345	-	-	-	See Monday
"	"	8459	069	No	Tropo Refract.	H	-	-	-	-	1300	-	1500	-	-	-	See Monday
Fri.	13/12	8240	07470	No	Tranet Readout	C	-	-	-	-	0000	0100	0200	-	-	-	-
"	"	8241	07470	No	Tranet Readout	C	-	-	-	-	1400	1500	1600	-	-	-	-
"	"	7243	1703C	Yes	Hound Dog Cap. Flt.	F	-	-	-	-	0100	0200	0230	-	-	-	AG M-28, B-52 Ellsworth etc.
"	"	7244	1703C	Yes	Hound Dog Cap. Flt.	F	-	-	-	-	0730	0830	0900	-	-	-	Same as 7243
"	"	8522	097	Yes	Bridge Gap	G+	-	-	-	-	0930	0930	1130	Delete	All support except optics	2/3/4/5	Optics 1.5,3.5,4.1,5.1, Timing. ARCPE follows.
"	"	8523	043C	No	GMCF #1 Boresight	H	-	-	-	-	1200	-	-	-	-	-	-
"	"	8524	1131E	No	Titan Gnd. Inst.	H	-	-	-	-	1200	-	-	-	-	-	Pad __ 1 shift, Pad __ 2 shifts delete Seq. & timing
"	"	8525	3630B	Yes	Gemini Gnd Inst.	F	275	NA	NA	16	1437	1500	1510	-	-	-	Pad __
"	"	8526	005B	Yes	LOKI II Launch	G	-	-	-	-	1600	1600	1635	-	-	-	Pad __
"	"	8527	2430D	Yes	Network Op. Readiness	F	6780	Yes	No	6	1200	1700	2100	-	-	-	Msl SA-5
"	"	8528	095B	No	SAC RBS	C	-	-	-	-	1700	-	2100	-	-	-	-
"	"	8529	2001A	Yes	MM Systems	D	447	Yes	No	5	1700	1900	1905	Delete	TLM 225.7, 252.4, 255.1 C/C	1/2.a./2x/2z	Msl No. 447, Silo __
"	"	8530	098E	Yes	Baloon track	G	-	-	-	-	1930	1930	2030	-	-	-	-
"	"	8531	098D	Yes	Nike Smoke Rocket	G	-	-	-	-	1930	1930	1933	Delete	Pre-Cal, Post Cal	2"1/2"b"	Pad __, Lch Az 060
"	"	8532	098A	Yes	Wind data	G	-	-	-	-	-	1930	-	-	-	-	W/8531
"	"	8533	2001B	Yes	Ordnance Test	D	447	Yes	No	5	2000	2100	2108	-	-	-	Msl No. 447, Silo __ Crit pwr T-100
"	"	8453	061H	No	Riometer Absorp.	H	-	-	-	-	0001	-	2359	-	-	-	See Mon.
"	"	8454	066B	No	STC CAT II Ops	G	-	-	-	-	0001	-	2359	-	-	-	See Mon.
"	"	8456	MS	No	Gemini	H	-	-	-	-	-	1200	-	-	-	-	See Mon.
"	"	8459	069	No	Tropo Refract.	H	-	-	-	-	1300	-	1500	-	-	-	See Mon.
Sat.	14/12	8242	07470	No	Tranet Readout	C	-	-	-	-	0000	0100	0200	-	-	-	-
"	"	8243	07470	No	Tranet Readout	C	-	-	-	-	1400	1500	1600	-	-	-	-
"	"	8453	061H	No	Riometer Absorp.	H	-	-	-	-	0001	-	2359	-	-	-	See Mon.
Sun.	15/12	8244	07470	No	Tranet Readout	C	-	-	-	-	0000	0100	0200	-	-	-	-
"	"	8245	07470	No	Tranet Readout	C	-	-	-	-	1400	1500	1600	-	-	-	-
"	"	8345	054	No	SCAVE	C	-	-	-	-	-	1100	-	-	-	-	Delete all support except Sta 91 timing to NAV VAC
"	"	8453	061H	No	Riometer Absorp.	H	-	-	-	-	0001	-	2359	-	-	-	See Mon.

Figure 11. (Continued)

machine form, it is logical to identify its several parts and the sequence of its development.

Several files in computer memory are required:

1. <u>Unique ID of equipment for Calendar Clocks File</u>:

Under the 95% rule, 7 basic pieces of equipment or instrumentation systems, classes, were identified. Each class has sub-systems -- town to individual items of hardware or frequencies. These basic systems and breakdown into sub-systems and components were initially prepared in outline form as shown typically in Figure 12. In turn, each meaningful outline level was assigned a unique 6-digit identification number (ID), also shown typically in Figure 12. As will be recalled, the pilot scheduling model was designed to accept schedule information and turn out a weekly schedule for a typical week. All instrumentation systems, sub-systems, and items of hardware in range inventory are thus to be represented by those required by identity and number to satisfy the test demands for the typical week. The list so compiled numbered 124 items which are uniquely identified in "clocks", equipments versus time, in computer memory. The purpose of the clocks, or in/out file, is to record the times that the individuals systems and/or item of equipment are set aside to

	Unique Identification Numbering System
1. Command	1-----
a. High Power/Lo Power	100001
b. Low Power	100002
2. Telemetry	2-----
a. Tel 2	21----
(1) TLM 18 Antennae	210100
(2) Tri helix antennae	2102--
(a)	210201
.	
.	
(d)	210204
(3) Seven turn antennae	210300
(4) Receivers (1401)	2104--
(a)	210401
.	
.	
(y)	210425
(5) 1/2" tape recorders	2105--
(a)	210501
.	
.	
(f)	210506
(6) SS & CE recorders	2106--
.	
.	
(c)	210603
(7) Combiners	2107--
(a)	210701
.	
.	
(c)	210703
(8) Discriminators	2108--
.	
.	
(9) Decoms (Parsons)	2109--
(a)	210901
.	
.	
(f)	210906

Figure 12. Seven Basic Classes of Resources Selected Under the 95% Rule and Subelements in Outline Form With Unique Identification Number System Shown

(10) DW Recorders	2110--
(a)	211001
.	
.	
(c)	211003
(11) Oscillographs	2111--
(a)	211101
.	
.	
(m)	211113
(12) Other	211200
b. Tel 3 (similar to Tel 2 above)	22----
c. Frequency	200300
d. Frequency	200400
.	
.	
f.f. Frequency	203300
3. S-Band Radar	3-----
a.	300001
.	
.	
c.	300003
4. C-Band Radar	4-----
a. 1.16 (Sta. 1)	410000
b. 0.18 (Sta. 0) (Not interchangeable except special circumstances	420000
5. Subcable w/o Supv. Control	500000
6. Impact Predictor Computer	600000
7. Subcable with Supv. Control	700000

Figure 12 continued

satisfy test demands. It also serves the purpose of identifying a conflict for a piece of test equipment required by another test for all or part of the same time period. In the event of conflict, the computer program searches further down the list in the "clocks" to see if other <u>identical</u> pieces of equipment in inventory are available for substitution. If so, the conflicting tests can be scheduled concurrently. Failing this, the program searches the "clocks" right and left for a no-conflict open slot and schedules or rejects the test accordingly. The clocks are maintained for each day. A fragment of the listing of the 124 unique items of equipment in the "clock" file is shown in Figure 13 in conjunction with a diagramatic sketch of in/out status.

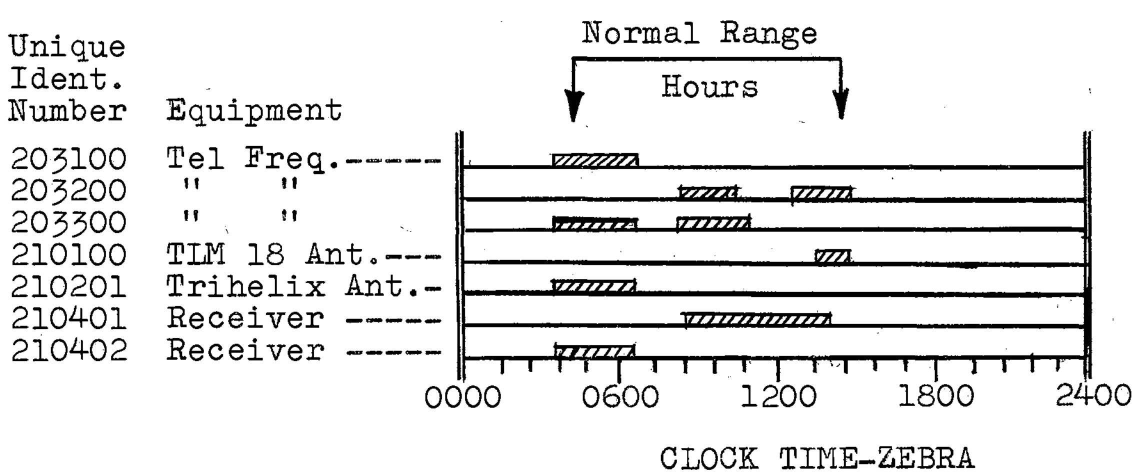

Figure 13. Fragment of the Listing of 124 Unique Items of Equipment in the "Clock" File and Representative In/Out Status

2. <u>OD Requirements File</u>:

Test requests identify individual Operational Directives (OD's), publications in which are listed the range equipments and frequencies required for conducting each test. In this file the equipments and frequencies identified by unique 6-digit numbers are listed for each OD to be involved in the selected week. A typical listing appears in Figure 14. The scheduling model plays each OD call-out against the "clock" file to arrive at a feasible schedule for each test or reject it as the case may be.

OD Number Selected ↓	Unique Ident. Number ↓	Equipment Identified by Unique Ident. Number
0970	210100	Telemetry, TLM 18 Antenna
0970	210601	" , SS and CF Recorder
0970	211200	" , Other Special Equipment
0970	203300	" , Frequency, 100.0 m.c.
0970	300001	S-Band Radar, 1st of 3 available
0970	410000	C-Band Radar, Station 1, one-only
0970	500000	Subcable w/o supv. control

Figure 14. Listing of Equipments and Frequencies Required and Unique Identification Numbers for a Typical OD Callout

3. <u>Frequency Table</u>:

In this table all command and telemetry

frequencies involved in the typical week, totaling 35, are listed versus the unique 6-digit identification number previously assigned in the "clock" and OD requirements files. A fragment of such a listing appears in Figure 15. The computer program, assuming it has arrived at a feasible no-conflict schedule for a test by playing the OD requirements against the "clock" file, will not schedule the test if any of the frequencies are within given ± limits of any other frequencies (16). The frequencies table provides the essential information for this conflict test by the computer program. In the event of frequency interference as specified by limits, the program searches right and left through a new cycle involving the OD requirements file, "clock" file, and frequency table finally scheduling or rejecting the test as appropriate.

Unique Ident. Number	Frequencies	
100300	100	Command Frequencies (Coded)
100400	120	
100500	180	
100700	220	
200300	2257	Telemetry Frequencies 225.7 mc--etc.
200400	2272	
200500	2282	
200600	2299	

Figure 15. Fragment of the Listing of 35 Command (Coded) and Telemetry Frequencies Involved in the Typical Week

4. Class table:

Seven basic pieces of equipment or instrumentation systems, classes, were previously mentioned as making up the inventory for the typical week. Test requests specify certain start and end times or T-0 times from which the span or duration of the test can be determined. These times establish the active test span. It takes a period of time to warm-up or pre-calibrate and post-calibrate equipments in addition to the test running item. These times vary with the class of equipment and, in some cases, with the configuration in which the equipment was operating for a prior test. A mean or conversative pre-calibration and post-calibration time for each class is listed in this table. See Figure 16. Before the scheduling program enters the "clock" file in an attempt to schedule an OD call-out, it increments the test start and end times with the appropriate pre-calibration and post-calibration allowances unique to the class of equipment or system involved and proceeds with scheduling steps as previously described.

Pre-calibration time increments in minutes	Post-calibration time increments in minutes	Class of Equipment
60	50	1. Command
50	20	2. Telemetry
60	60	3. S-Band Radar
90	45	4. C-Band Radar
30	30	5. Subcable w/o supv. control
150	30	6. Impact predictor computer
105	30	7. Subcable with supv. control

Figure 16. Pre-calibration and Post-calibration Times for Seven Basic Classes of Equipment Selected Under the 95% Rule

5. Replacement table:

A conflict for a piece of equipment in the "clock" file may be resolved by search for another piece of equipment which is not busy during otherwise conflicting times of two or more tests. If so found, the tests may be scheduled concurrently assuming no frequency interference. In some cases, only one-of-a-kind of an inventory item exists and conflicts in its use cannot be so resolved. In particular circumstances, one or more other dissimilar equipments may be assembled to substitute in performance for the one-only item in conflict. The machine program has appropriate flags to identify such circumstances of dissimilar permissible substitution. Tests in conflict for one-only pieces of equipment and so flagged cause the computer routine to revert to the replacement table to search for the approved substitute combination. Having identified an approved substitution, the machine scheduling of a test in original conflict with another proceeds as previously described. See Figure 17. The figure, as interpreted by the computer, says: When a test request involving OD 098E is to be scheduled, if it is in conflict with another test calling out the Station 1, C-Band radar, 1.16, unique identification number 410000, then a Station 1 S-Band radar for initial tracking, unique ID 3000001 and a C-Band radar, unique ID 420000, at Patrick Air Force Base, Station 0, may be combined as a substitute to satisfy OD 098E requirements.

OD Number	Sta. 1 C-Band	Sta. 1 S-Band	Sta. 0 C-Band	
0985	410000	300001	420000	2

Figure 17. A Listing of Combinations of Equipment Which are Technical Substitutes for a One-Only Piece of Equipment in the Basic Seven Classes Selected Under the 95% Rule

Date cards, heading cards, short titles, and remarks, in conjunction with the input and files described, constitute the base for the machine scheduling program from test requests input to weekly schedule output.

Test requests enter the computer sorted by days; the computer scheduling model completes the scheduling in four passes as shown in Figure 18.

Pass I: Sorts tests by categories within days and priorities within categories (14).

Pass II: Schedules all launches for each day and the whole week.

Pass III: Schedules tests requiring common range equipment and those requiring no common range equipment.

Pass IV: Sorts and prints the weekly schedule by categories by days with identifying short titles, remarks, and other pertinent data.

In the process of scheduling, the computer prints out, as it encounters them, tests which may be rejected for many reasons. Some reject notifications are listed below:

Reject no category: If test request line entry is inadequately filled out in this respect.

Reject overload: If the number of launch tests requested in any one day exceed capacity of the range and scheduling model.

Reject no shift: If a launch has an hours window and cannot be shifted to a no-conflict time relative to a priority test previously scheduled.

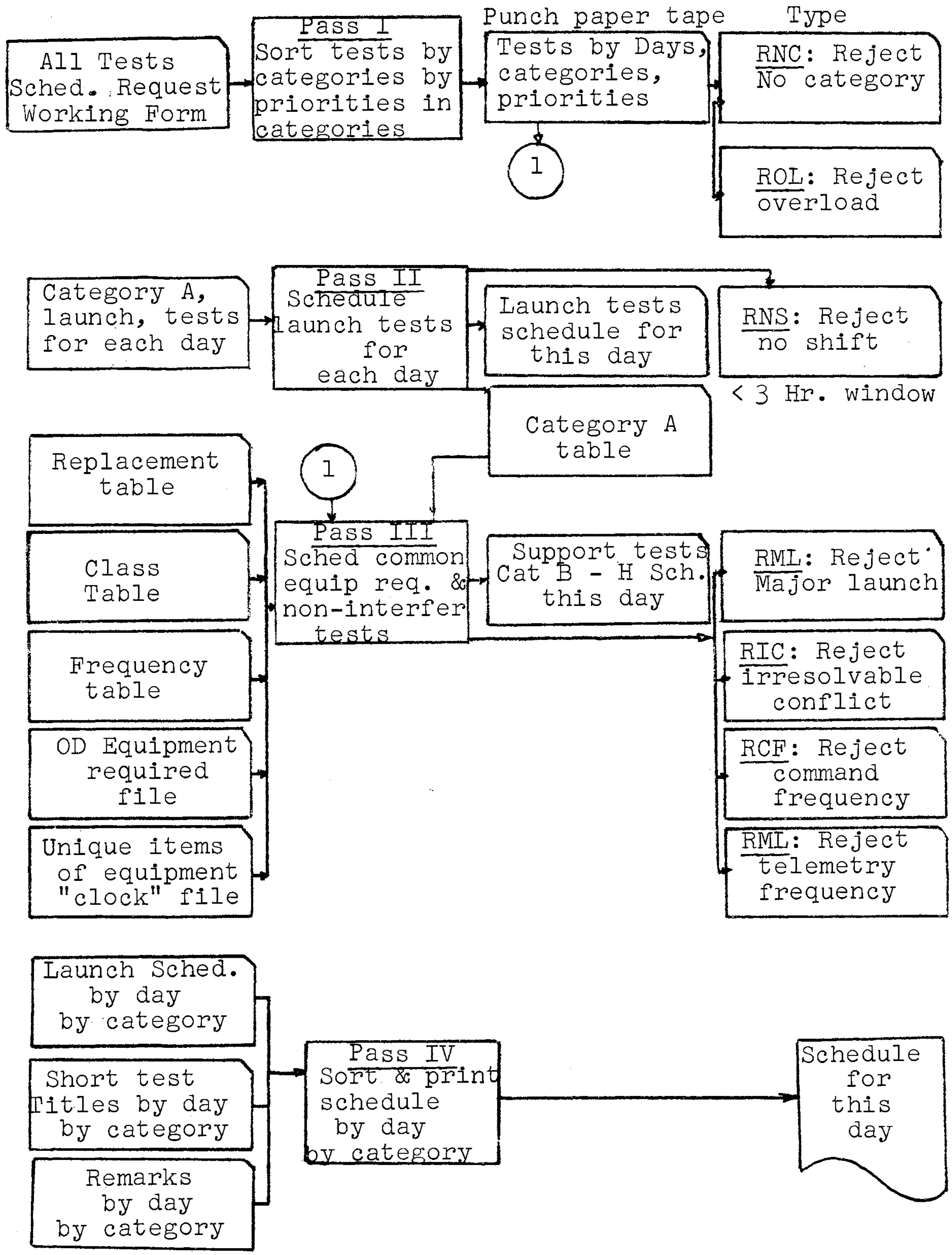

Figure 18. Logic Flow Diagram Showing the Four Passes Making up the Computer Scheduling Program

Reject major launch: If a down range only or other support test not directly associated with the launch conflicts in time with the major launch.

Irresolvable conflict: If a test cannot be scheduled after an exhaustive search for a no-conflict blank spot within range hours.

Reject frequency: If a frequency conflict is identified. The machine program continues the search for no-conflict slot and schedules or rejects as Irresolvable conflict as appropriate.

It needs to be emphasized here that much more astute scheduling capability and finesse has been built into the computer scheduling program than required to satisfy the demands for scheduling the typical week's test request load, e.g., the capacity to accept and schedule up to three launch tests in any one day. While so scheduling, the model will check on the latitude to slip or advance T-times based on window tolerances and shift them out of conflict while staying within or minimizing overtime range hours.

Relative to support tests, assuming that the model has selected a technical equivalent combination of equipments for a basic equipment in conflict and, in turn, finds that the technical equivalent combination is in conflict in whole or in part, it will play both alternately against the "clock" file in the search for a blank spot and select the basic equipment or the substitute for scheduling whichever first clears the double conflict. Many other features and capabilities have been provided in the model to handle situations which have been and may be encountered outside the typical week.

Original logic flow diagrams are included in Appendix B, Figures 20 through 31. The functions of various routines and sub-routines are appropriately identified. From these, detailed machine logic flow diagrams were developed. These are broken down by passes as identified above and presented in Appendix C, Figures 32 through 36.

Descriptive materials have been included in Appendices B and C only where appropriate to give continuity and perspective to the various functional parts of the logic diagrams. Such description is not exhaustive. Rather, it is intended that the body of the dissertation provide the major source of appreciation of the logic and flow of the functional parts of the scheduling operation and its translation into routines and sub-routines designed and assembled to perform the scheduling operation.

Finally, the weekly schedule output for the typical week is shown in Figure 19. It does not agree in format with the weekly schedule, Figure 9, as it is presently prepared and distributed by the Schedule Control Office.

In the manually derived test schedule, Figure 9, it may be noted that the tests are listed by day more-or-less in the chronology of their T-times or start times. In some cases, this chronological ordering is violated, e.g., 1-09/12/63

TEST	OD	C	WTST	S	T	E	
8232	10747.0	3	-1	0	100	200	
TRANET READOUT							
8233	10747.0	3	-1	1400	1500	1600	
TRANET READOUT							
8460	95.1	3	-1	1345	-1	1715	
SAC RBS							
8463	1105.2	4	3787	1634	1700	1715	
TITAN IX							
PAD--, MSL. NO. N-29							
8465	166.0	4	-8463	0	0	0	
MDS							
W/8463							
8464	1131.1	4	-8463	0	0	0	
TITAN SIM. FLT.							
W/8463							
8461	69.1	7	-1	-1	1630	-1	
INCOR TEST NO							Note 2
8468	98.5	7	-1	1930	1930	2030	
BALOON TRACK							
8469	98.4	7	-1	1930	1930	1933	
NIKE SMOKE ROCKET							
PAD- LCH. AZ. 060							
8470	98.1	7	-8469	-1	0	-1	
WIND DATA							
W/8469							
8455	97.0	7	-1	930	-1	1130	
BRIDGE GAP							
OPTICS SITES 1.5, 3.5, 4.1, 5.1. TIMING. ARCPE FOLLOWS							
8466	68.1	7	-1	1630	1700	1830	
CARDE A/B							
CF-100 STAGE PAFB							

Figure 19. The Computer Schedule of Tests and Reject Notifications for a Typical Week

8462 5.2 7 -1 1600 1600 1634
LOKI II LAUNCH
PAD--

8454 66.2 7 -1 0 -1 2358
STC CAT. II OPS.
TRI 40 HRS.BOM DISC.,DELETE STA. 91

8471 97.0 7 -1 2230 -1 30
BRIDGE GAP
OPTICS SITES 1.5, 3.5, 4.1, 5.1. TIMING. ARCDE FOLLOWS

8452 .9 8 -1 0 -1 2358
GEMINI
W/B PAIRS LOOPED SIM. LENGTHS. NO O/T AUTHORIZED

8453 61.8 8 -1 0 -1 2358
RIOMETER ABSORP.

8467 95.2 8 -1 1745 -1 2100
SAC RBS

8457 93.3 8 -1 1200 -1 -1
GMCF NO. 1 BORESIGHT

8458 1131.5 8 -1 1200 -1 -1
TITAN GND. INST.
PAD-- 1 SHIFT. PAD-- 2 SHIFTS.

8459 69.0 8 -1 1300 -1 1500 Note 2
INCOR TEST NO

8456 .9 8 -1 1130 -1 345
GEMINI
SEQ. OP. TO BH. O/T AUTHORIZED

2-10/12/63

TEST OD C WTST S T E

8481 1131.3 2 3787 0 -1 -1
TITAN TANKING
PAD--, MSL. NO. N-29

8482 1131.4 2 3787 0 -1 -1
TITAN TANKING
PAD--. MSL. NO. N-29

Figure 19 continued

8479	95.2	3	-1	1730	-1	2045	
SAC RBS							
8234	10747.0	3	-1	-1	100	-1	
TRANET READOUT							
8235	10747.0	3	-1	-1	1500	-1	
TRANET READOUT							
8477	61.7	3	-1	-1	1400	-1	
INCOR TEST NO							
8476	95.1	3	-1	1345	-1	1715	
INCOR TEST NO							Note 2
8260	203.1	4	6666	1449	1649	1739	
POLARIS DRY RUN							
MSL. 46 DOCK ONLY, MOPS 12,DELETE COMM NETS,AZUSA R/OS							
8475	2532.0	5	5332	1849	-1	2249	Note 3
DELTA ACCEPTANCE							
NO. 22,PAD--,SC RAD CLNC. ON 136.23/.92/.95,235.0,-ЖСЖ							
8478	1230.0	6	575	1500	-1	-1	
ATLAS TANKING							
NO.137F, PAD--, A/F TLM RAD CLNC 1800Z LOX. NIB 8475							
8454	66.2	7	-1	0	-1	2358	
STC CAT II OPS.							
SEE MONDAY							
8472	93.6	7	-1	2230	0	400	
G/E AIRBORNE							
C-131 NO. 803. FLT PLANS G AND Q2. T/O T-60							
8480	98.5	7	-1	1930	1930	2030	
BALOON TRACK							
8453	61.8	8	-1	0	-1	2358	
RIOMETER ABSORP.							
SEE MONDAY							
8473	1131.5	8	-1	1200	-1	-1	
TITAN GND. INST.							
PAD-- 1 SHIFT, PAD-- 2 SHIFTS, DELETE SEQ. + TIMING							

Figure 19 continued

```
 8456           .9  8       -1       -1     1200       -1
GEMINI
 SEE MONDAY

 8459         69.0  8       -1     1300       -1     1500
TROPO. REFRACT.
 SEE MONDAY

 8474         93.3  8       -1     1200       -1       -1
GMCF NO. I BORESIGHT


 3-11/12/63
 TEST         OD   C    WTST        S        T        E

 3787       1105.0  1     1105     1649     2000     2100
TITAN II LAUNCH
MSL.N-29,PAD--, LCH.AZ. 85, FLT.AZ. 106. 60 MN BIH ETC

 8510          5.7  2     1105       -1     2000       -1
ARCAS ROBIN LAUNCH
OR T-180 STA. 12

 8495          8.0  2     1105       -1     2000       -1
DRD SPEC. TEST
BRIEF NO. 56 SITES--, ETC.

 8496          9.0  2     1105       -1     2000       -1
A/B RAD. MON.
C-131 ACFT. T/O PAFB T+60

 8497         51.0  2     1105       -1     2000       -1
FLYING DUTCHMAN
C-131 ACFT. STAGE PAFB STA 1, MOD II RADAR

 8011         60.2  2     1105       -1     2000       -1
SPP

 8498         61.1  2     1105       -1     2000       -1
OAR SDT

   -1         61.2  2    -8498       -1     2000       -1
OAR SDT

   -1         61.3  2    -8498       -1     2000       -1
OAR SDT
```

Figure 19 continued

8504 166.0 2 1105 -1 2000 -1
MDS

8499 68.0 2 1105 -1 2000 -1
CARDE A/B
CF-100 STAGE STA. 1, FLT. PLAN 1-160-40, MOD II

8500 73.0 2 1105 -1 2000 -1
NIKE ZEUS
STA. 12 CODE 10, EC-121 ACFT.

8501 80.3 2 1105 -1 2000 -1
NAVY GED

8502 84.0 2 1105 -1 2000 -1
RAMP
KC-135 ACFT F/P 1-195-40, OPTICS V/M, STA. 1, MOD II

8503 162.0 2 1105 -1 2000 -1
DC-6 RAD.
DC-6 STAGE ASC

8505 177.0 2 1105 -1 2000 -1
ARMY ACOUSTIC

8506 179.0 2 1105 -1 2000 -1
ARMY BACKSCATTER

8509 5.4 2 1105 -1 2000 -1
ARCAS ROBIN LAUNCH
OR T-120 PAD--

8508 185.0 2 1105 -1 2000 -1
LRFDT

8507 181.0 2 1105 -1 2000 -1
RFDT

8276 232.7 2 6666 1709 -1 -1
LORAC CRUISE
LORAC A STABLE T-470 UNTIL EAG PORTS 12/1300Z

8236 10747.0 3 -1 -1 100 -1
TRANET READOUT

Figure 19 continued

8492 95.2 3 -1 1745 -1 2100
SAC RBS

8237 10747.0 3 -1 -1 1500 -1
TRANET READOUT

8274 232.8 4 6666 1509 -1 -1
STARTRACKER CALIB
W/6666 OR T-590/6666 UNTIL EAG UNDWAY. DELETE COMMAND

8494 98.1 7 -8493 -1 0 -1
WIND DATA
W/8493

8483 93.6 7 -1 2330 0 400
GE AIRBORNE
C-131 NO. 803, FLT. PLANS G AND Q2

8454 66.2 7 -1 0 -1 2358
STC CAT II OPS.
SEE MONDAY

8484 97.0 7 -1 930 -1 1130
BRIDGE GAP
OPTICS SITES 1.5, 3.5, 4.1, 5.1. TIMING. ARCPE FOLLOWS

8487 68.1 7 -1 1130 1200 1330
CARDE AIRBORNE
CF-100 PAFB, STA 1 MOD II RADAR

8486 1131.5 8 -1 1200 -1 -1
TITAN GND. INST.
PAD-- 1SHIFT, PAD-- 2 SHIFTS. DELETE SEQ. AND TIMING

8490 69.1 8 -1 1630 -1 1830
INCOR TEST NO Note 2

8459 69.0 8 -1 1300 -1 1500
TROPO REFRACT.
SEE MONDAY

8488 95.1 8 -1 1345 -1 1715
INCOR TEST NO Note 2

8453 61.8 8 -1 0 -1 2358
RIOMETER ABSORP.
SEE MONDAY

Figure 19 continued

8485 93.3 8 -1 1200 -1 -1
GMCF NO. 1 BORESIGHT

8456 .9 8 -1 -1 1200 -1
GEMINI
SEE MONDAY

4-12/12/63

TEST	OD	C	WTST	S	T	E
6666	203.0	1	6666	2209	100	200

POLARIS++++ LAUNCH
MSL---46, FLT AZ 115, EA6 UNDWY. T-410 ETC.

8074	9.0	2	6666	-1	100	-1

A/B RAD. MON.
C-130 ACFT STDBY PAFB T-60, WX OBS W/COMM TO CC WX CON

8520	20.0	2	6666	-1	100	-1

A/B TLM ANT. CHECKOUT
C-130 ACFT. NO. 628 STAGE ACS PHASE III

8076	51.0	2	6666	-1	100	-1

FLYING DUTCHMAN

8077	61.1	2	6666	-1	100	-1

AF GED

-1	61.2	2	-8077	-1	100	-1

AF GED

-1	61.3	2	-8077	-1	100	-1

AF GED

8078	80.3	2	6666	-1	100	-1

NAVY GED

8079	84.0	2	6666	-1	100	-1

RAMP
KC-135 STAGE WPAFB F/P 1+040+32 OPTICS V/M STA 1 MOD I

8080	163.0	2	6666	-1	100	-1

GOST
STA 1 ONLY. DELETE ALL SUPPORT EXCEPT GREEN PHONES ETC

Figure 19 continued

8081	170.0	2	6666	-1	100	-1
AREX. OPNS.						
8082	177.0	2	6666	-1	100	-1
ARMY ACOUSTIC						
8084	179.0	2	6666	-1	100	-1
ARMY BACKSCATTER						
8083	181.0	2	6666	-1	100	-1
RFDT						
8085	185.0	2	6666	-1	100	-1
LRFDT						
8086	240.0	2	6666	-1	100	-1
PX INST. SUPPORT PHASE II						
9325	5031.0	2	6666	-1	100	-1
GLOTRAC TRACKING STA 1, 5, 7, 91, BDA, ATL.						
8516	95.2	3	-1	1745	-1	2100
SAC RBS						
8238	17470.0	3	-1	-1	0	-1
TRANET READOUT						
8239	17470.0	3	-1	-1	1500	-1
TRANET READOUT						
8513	95.2	3	-1	1345	-1	1715
SAC RBS						
8514	61.7	3	-1	1300	1400	1500
ATLANTIC DUCT TRINIDAD RADAR 2 HRS.						
8454	66.2	7	-1	0	-1	2358
STC CAT II OPS. SEE MONDAY						

Figure 19 continued

8512 1131.5 8 -1 1200 -1 -1
TITAN GND. INST.
PAD-- 1 SHIFT, PAD-- 2 SHIFTS, DELETE SEQ. AND TIMING

8453 61.8 8 -1 0 -1 2358
RIOMETER ABSORP.
SEE MONDAY

8511 93.3 8 -1 1200 -1 -1
GMCF NO. 1 BORESIGHT

8456 .9 8 -1 1130 -1 345
GEMINI
SEE MONDAY

8459 69.0 8 -1 1300 -1 1500
TROPO REFRACT.
SEE MONDAY

5-13/12/63

TEST OD C WTST S T E

8240 10747.0 3 -1 0 100 200
TRANET READOUT

8241 10747.0 3 -1 1400 1500 1600
TRANET READOUT

8528 95.2 3 -1 1700 -1 2100
SAC RBS

8529 2001.1 4 447 1700 1900 1904
MM SYSTEMS
MSL NO. 447, SILO--

8533 2001.2 4 447 2000 2100 2107
ORDNANCE TEST
MSL NO. 447, SILO--, CRIT. POWER T-100

7244 1703.3 6 -1 730 830 900
HOUND DOG CAP FLIGHT
SAME AS 7243

7243 1703.3 6 -1 100 200 230
HOUND DOG CAP FLIGHT
AGM-28, B-52 ELLSWORTH ETC.

Figure 19 continued

8527	2430.4	6	6780	1200	1700	2100	
NETWORK OP READINESS							
MSL SA-5							
8525	3630.2	6	275	1436	1500	1509	Note 4
GEMINI GND. INST.							
PAD--							
8522	97.0	7	-1	930	930	1130	
BRIDGE GAP							
OPTICS SITES 1.5, 3.5, 4.1, 5.1. TIMING. ARCPE FOLLOWS							
8526	5.2	7	-1	1600	1600	1634	
LOKI II LAUNCH							
PAD--							
8531	98.4	7	-1	1930	1930	1933	Note 4
NIKE SMOKE ROCKET							
PAD--, LCH. AZ. 060							
8530	98.5	7	-1	2119	2119	2219	
BALOON TRACK							
8454	66.2	7	-1	0	-1	2358	
STC CAT II OPS.							
SEE MONDAY							
8532	98.1	7	-8531	-1	0	-1	
WIND DATA							
W/8531							
8524	1131.5	8	-1	1200	-1	-1	
TITAN GND. INST.							
PAD-- 1 SHIFT, PAD-- 2 SHIFTS, DELETE SEQ. AND TIMING							
8453	61.8	8	-1	0	-1	2358	
RIOMETER ABSORP.							
SEE MONDAY							
8523	93.3	8	-1	1200	-1	-1	
GMCF NO. 1 BORESIGHT							
8456	.9	8	-1	-1	1200	-1	
INCOR TEST NO							Note 2
8459	69.0	8	-1	1300	-1	1500	
TROPO REFRACT							
SEE MONDAY							

Figure 19 continued

6-14/12/63

TEST	OD	C	WTST	S	T	E
8242	10747.0	3	-1	0	100	200
TRANET READOUT						
8243	10747.0	3	-1	1400	1500	1600
TRANET READOUT						
8453	61.8	8	-1	0	-1	2358
RIOMETER ABSORP. SEE MONDAY						

7-15/12/63

TEST	OD	C	WTST	S	T	E
8244	10747.0	3	-1	0	100	200
TRANET READOUT						
8245	10747.0	3	-1	1400	1500	1600
TRANET READOUT						
8345	54.0	3	-1	-1	1100	-1
SCAVE DELETE ALL SUPPORT EXCEPT STA. 91. TIMING TO NAVFAC						
8453	61.8	8	-1	0	-1	2358
RIOMETER ABSORP. SEE MONDAY						

NEW PAGE, THREAD DATA ROLL

Machine reject notices and notes concerning them follow:

Figure 19 Continued

RML 1112	203.1	1	6666	0	7	1300	-1	1500	1	223	227	1	0	8271	3	4	4
RML 1112	2430.4	1	6780	1	6	1200	1700	2100	0	0	0	0	0	8491	3	6	4
RML 1112	98.4	1	-1	0	0	1950	1950	1955	1	-3	0	0	0	8493	3	7	4
RML 1112	98.5	1	-1	0	0	1400	1400	1500	0	0	0	0	0	8489	3	7	4

RML 1212	2400.1	1	6780	1	6	1600	1750	2000	0	0	0	0	0	8515	4	4	4
RML 1212	2533.0	1	5332	1	9	1800	-1	2000	0	0	0	0	0	8517	4	5	4
RML 1212	93.6	1	-1	0	0	2251	-1	2401	0	0	0	0	0	8521	4	7	4
RML 1212	98.5	1	-1	0	0	1950	1950	2050	0	0	0	0	0	8518	4	7	4
RML 1212	68.1	1	-1	0	0	1900	1950	2100	1	3	5	0	0	8519	4	7	4

1. RML (Reject Major Launch): The machine program rejected these support tests as instructed based on overrun of 2 1/2 hour limit prior to launch test entering Range countdown. In practice, these tests were scheduled with their end times approaching within 1 1/2 hours of Range count time of major launch. This suggests a revision of the limit, fixed or variable, to fit circumstances or its enforcement.

Figure 19 Continued

2. Incorrect Test Number: Machine program identified that no data for Short Titles and Remarks had been provided to go along with test number--but scheduled tests anyway. In another test case, the machine program identified that the category of test as inserted was in error and was unable, therefore, to find a matching Short Title and Remarks.

FC	2532.0	228.2	1217	1733	227.2
FC	2532.0	234.0	1217	1733	234.0
FC	2532.0	234.0	1217	1733	234.0
FC	2532.0	234.0	1242	1758	234.0
FC	2532.0	234.0	1267	1783	234.0
FC	2532.0	234.0	1292	1808	234.0
FC	2532.0	234.0	1317	1833	234.0
FC	2532.0	234.0	1342	1858	234.0
FC	2532.0	234.0	1367	1883	234.0
FC	2532.0	234.0	1392	1908	234.0
FC	2532.0	234.0	1417	1933	234.0
FC	2532.0	234.0	1442	1958	234.0
FC	2532.0	234.0	1467	1983	234.0
FC	2532.0	234.0	1492	2008	234.0
FC	2532.0	234.0	1517	2033	234.0
FC	2532.0	234.0	1542	2058	234.0
FC	2532.0	234.0	1567	2083	234.0
FC	2532.0	234.0	1592	2108	234.0
FC	2532.0	234.0	1617	2133	234.0
FC	2532.0	234.0	1642	2158	234.0
FC	2532.0	234.0	1667	2183	234.0
FC	2532.0	234.0	1692	2208	234.0
FC	2532.0	234.0	1717	2233	234.0
FC	2532.0	234.0	1742	2258	234.0
FC	2532.0	234.0	1767	2283	234.0
FC	2532.0	234.0	1792	2308	234.0

3. FC (Frequency Conflict): The machine record shows that the attempt to schedule OD 2532 on Tuesday was initially rejected because of a ± 1.5 mc. telemetry frequency conflict with a prior test scheduled on 228.2 mc; also shows a direct conflict on 234.0 mc. The Machine program then attempted a left shift but ran into a range hours limit, then shifted right advancing the start time of test, OD 2532, by 15 minutes, performed frequency conflict checks with each such shift until an open slot was found--finally scheduled the test to enter Range count at 1849Z (1759Z incremented by preparation time).

Figure 19 continued

⟶	4C	210401	Receiver (1401)	OD 3630 B
⟶	4C	210402	Receiver (1401)	
⟶	4C	210501	1/2" Tape Recorder	
⟶	4C	210502	1/2" Tape Recorder	
⟶	4C	300001	S-Band Radar	OD 098 D

4. 4C: Only three entries or "use times" were provided in calendar "clocks" because of limited memory and the desire to test the program should the number of entries (separate test usages of a unique item of equipment) exceed 3. The machine record shows that OD's 3630B and 098D on Friday were the fourth tests respectively involving the equipments identified by unique ID numbers. The program printed out the "4C" overflow notice to the Chief Scheduler and, however, scheduled tests at requested T-times subject to manual verification.

Figure 19 Continued

when two identical tests are to be run at different times during the day or, similarly, when two or more tests are related. In these cases, the tests are grouped in the otherwise chronological listing.

The machine developed test schedule is printed out by days by category. Several fortunately compatible reasons for this difference in format are presented. First, the machine Weekly Schedule format conforms to limitations of the 1620 computer print-out system involved. Second, remembering that the machine derived schedule is initially to aid human schedulers, the print-out of scheduled tests by categories followed by reject notifications is concluded to be the most appropriate form for ease of correlation, cross checking, and final scheduling arrangements by scheduling officers. Third, the memory capacity of the 1620 available has been pushed to the limit to contain the necessary files and the complex scheduling program. A sub-routine for odering the tests for print-out in chronological order, grouping related tests, or any other format desired can be easily written and appended to the basic computer program when employed on a machine of larger capacity.

Though of different format, the machine derived Weekly Schedule and the human derived Weekly Schedule are identical except in those cases where differences were intentionally included in the computer program. The most significant of these differences, it will be recalled, is that the computer program having identified a conflict in frequencies, prints out a temporary reject notification and proceeds to search for a free slot to arrive at a no-conflict schedule. This is done for the Chief Scheduler so that he may decide which alternative of several to use in completing his scheduling function. In the above case, he may choose to take the machine solution and clear the revised test times with the Program Office affected. He may choose to schedule the tests technically in conflict to be run simultaneously if random read-out, no-conflict control, is to be exercised by the Superintendent of Range Operations. Other alternatives are available to him. It should be pointed out that even though the machine scheduling program was designed to the Chief Scheduler's specification with respect to radiating frequencies and flagging conflicts for his attention, it originally contained a method for identifying "exclusive" and "readout" demands for frequencies and other equipments. It would have possessed the capability for scheduling by slipping tests out of the conflict range or running them simultaneously in technical conflict respectively. Thus, it would have operated to select and schedule tests using one of the alternatives reserved for the scheduling officer as described above.

In summary, the factors underlying the heretofore "shadow" priorities system at play in the scheduling process were identified and reassembled in the form of an algorithm. The Scheduling Request Working Form for scheduling officers, Figure 11, designed to satisfy the machine scheduling program, has been presented. Test requests and supporting data entered by line item on this form, converted to cards (tapes) as the basic input to the scheduling model, have been identified as a sequential step. Over-all development of the computer scheduling model from logic flow to machine program has been described. The ability of the computer scheduling program to print-out a Weekly Schedule for a typical week in different format but identical in content with the human developed Weekly Schedule, with the exception of design differences noted, has been demonstrated.

CHAPTER V

THE PILOT COMPUTER SCHEDULING MODEL: ITS EVOLUTIONARY USE FOR ANALYSIS OF THE MAN-MACHINE COMBINATION FOR OPTIMUM SCHEDULING EFFICIENCY

The major contribution of the research effort described has been to demonstrate that computer scheduling to satisfy a probabilistic demand in a heuristic environment is possible with degree of automation only remaining to be resolved. The pilot model, with moderate expansion and adaption to a larger computer, can be of substantial aid to scheduling officers in the preparation of Weekly Schedules. A significant portion of its immediate value lies in its ability to identify and flag equipment and frequency conflicts -- particularly those associated with destruct systems on missiles and spacecraft. Various other uses are its application in the training of scheduling officers, delineation of a set of rules of engagement in scheduling processes, and use in the analysis of equipment utilization and requirements.

The most significant value of the pilot model, however, lies in its potentiality as a means for determining the optimum man-machine combination on a sound cost/effectiveness basis at each evolutionary step in its development and application. This is particularly true if one considers the future missile and spacecraft launch and support test work-load. It is not possible at this writing to specify the over-all man-machine combination to yield optimum scheduling efficiency for the Atlantic Missile Range.[1] It is possible to identify and outline the transitional steps for modifying, expanding, and working the model to exploit the research to date:

1. Convert the 1620 pilot scheduling program to a 7094 program.
2. Continue the use of the limited range inventory of equipment; that is, plan on manipulating the scheduling model using the seven classes of equipment previously identified as responsible for 95% of scheduling conflicts encountered -- the 95% rule.
3. Expand the OD requirements file for OD's which will be encountered in the forseeable future, say six months.
4. Expand the <u>Unique ID of Equipment Calendar Clock File</u>, <u>Frequency Table</u>, and <u>Replacement Table</u> accordingly.

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[1]Since submission of this dissertation in final draft, the Secretary of Defense has ordered the establishment of a National Range Division for central management of all National Ranges on a global basis. This gives a new dimension to the scheduling problem and the significance of automation.

5. In conference with the Chief Scheduler, select a future week, supply the machine Scheduling Request Working Forms to the Scheduling Control Office, monitor their appropriate execution, prepare appropriate input cards (tapes), and exercise the scheduling model to produce a Weekly Schedule.
6. Compare the computer schedule with the manual one which has proceeded currently. Identify and evaluate desirable and undesirable differences. Be alert to other features which may be incorporated in the model to provide additional aid to schedulers.
7. Repeat steps 2 through 6 until a sound working knowledge of the time, effort, and payoff of computer scheduling is acquired relative to the existing location of the Scheduling Control Office, the computer used, its accessibility, availability of software and delivery support, timeliness of the product, etc. Superimpose this working knowledge onto a more efficient and achievable computer service arrangement for further analysis in terms of timeliness, payoff and cost.
8. Consider modifications to the computer scheduling model such as the inclusion of other classes of equipment beyond the basic 7, down

range stations, etc., previously excluded by the 95% rule. Analyze the storage capacity required for the "clock file", the OD requirements file, and other files assuming that a full fledged computer scheduling model is to be embraced. From this and vantage point, analyze cost/effectiveness of the system at each evolutionary step relative to the present, intermediate (6 to 18 months) and future scheduling work-loads. (A critical consideration throughout should be the use of the scheduling model in each of its evolutionary configurations not only to satisfy the Weekly Scheduling phase, but, to support the Real Time Scheduling phase involving cancellations, additions, and modifications of tests on a day-to-day, hour-to-hour, and minute-to-minute basis in the active test week.)

9. Finally, analyze computer scheduling as an assist in the scheduling process in terms of its cost/effectiveness assuming the provisions of a computer solely for the scheduling function or, remote read in/out devices and time shared rapid access to computers serving other functions.

Such evolutionary development, though conservative in terms of the build-up of the number of computer systems people and computer usage, may not be so considered from the standpoint of the increased discipline which computer usage will impose on scheduling officers. An example is the faithful filling of the newly proposed Scheduling Request Working Form.

This form requires the entry of start and end times of tests if such tests require range common equipment in one or more of the seven classes identified. In present practice, the entry of a T-0 time is adequate to the needs of the human scheduler who mentally adds start and end times derivable from the OD or from experience and scans the test request board with these augmenting times in mind in the process of visually inspecting for conflicts. The columnar headings of the Schedule Request Working Form, Figure 11, identify the requirement for insertion of other data or instructions which the scheduling officer at present only considers and integrates mentally in performing his scheduling function.

The nature of the problem, particularly its heuristic properties, has required that every effort initially be exerted to model the scheduling operation as it is. This is not to say that major-to-minor changes in procedures for receiving test requests and scheduling tests can or should be avoided. The above sets the stage for three concluding remarks:

1. The pilot scheduling model, itself, can be used as a vehicle for recognizing, testing and

instituting worthwhile changes in the scheduling process.

2. By faithfully sticking to the modeling of scheduling operations as they are, a minimum of changes in procedure to fit the requirements imposed by computer applications will initially be introduced. Though inefficient in some respects, the price is worth the result in terms of avoiding early difficulties and disruption of existing scheduling practices.

3. However, a computer application to a resources management problem ultimately demands its pound of flesh for by its very nature it forces a discipline and conformity on the user -- changes in the way of doing things -- which he may not have anticipated and may be ill disposed to accept. There is nothing so resistant to proposed change as a successful operation and present methods of scheduling are successful by subjective standards.

Stillson (15) treats the subject of "Implementation of Problems in O.R." with vigor and finesse concluding that this is truly one of the most neglected vital considerations in the spectrum of Operations Research endeavors.

In summary, the research described in the preceding chapters has been confined to the development of a pilot scheduling model useful in its present form when adapted to a machine of larger memory and higher output capacity. It has been stated that the model contains all the practical features -- encountered in the research effort -- for evolutionary expansion and exploitation to serve the purpose of analyzing and determining the optimum man-machine combination for the Atlantic Missile Range. The evolutionary steps to an idealized goal have been listed in conjunction with factors and circumstances to be involved in phased cost/effectiveness studies. Some conclusions were given at the outset concerning early usefulness of the machine scheduling model as an aid in the scheduling process. These must be qualified by such considerations as computer location and accessibility, in-line software support, and surface delivery service of input/output data. Reference has been made to the discipline which schedulers must understand and faithfully observe if computer scheduling is to be successful.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The hypothesis contained in the original proposal for research approved by the committee reads:

> "that there is a combination of human intelligence and computer application which may be assembled for most efficient handling of the Range [any complex] scheduling problem."

This hypothesis was developed from exposure to conflicting beliefs at responsible levels of management that the missile, spacecraft, and support test scheduling function could and could not be performed by computers.

The "could" advocates based their beliefs on the observation that electronic computers had been repeatedly applied successfully in other complex resources management situations. They further reasoned that the process of scheduling consisted of knowing resources available, the Range inventory; resources required, specified in Operational Directives (OD's) for each test and program current on the Range; and test times required, submitted with each test request. They concluded that with these "knowns", a machine was well suited to the task of performing a scheduling operation. This was called the "outsider" point of view throughout the dissertation.

The "could not" advocates were people directly involved in or acquainted with the manual scheduling process. They reasoned that Operational Directives (OD's) were a departure point for scheduling in a real world involving innumerable compromises, judgments, and negotiations with test requestors that a computer cannot handle. The latter group, then, believed that the heuristic atmosphere in which test scheduling operates could not be broken down into factors or networks of factors underlying scheduling decisions; that no algorithm adaptable to computer programming was possible. This was referred to as the "insider" point of view throughout the dissertation.

The research described in this dissertation was embraced to establish, first, whether the sources of the heuristic judgments could be identified and put in the form of algorithms, second, whether the scheduling process could be duplicated through development and use of a machine program, and third, the degree to which computers could be efficiently employed in the scheduling process.

The introductory chapter records that the over-all objective of research was the development of a pilot model for actual scheduling operations to be useful in determining an optimal man-machine combination on a much larger scale. The results of the search of literature were shown to be more productive in revealing that classical and applied attacks on scheduling problems to date were not particularly helpful relative to the problem described than otherwise may have been anticipated.

In Chapter II the relationships of the Department of Defense, Range users, and the Air Force Missile Test Center as the Executive Agent for the Atlantic Missile Range were developed. The steps by which the Range is involved in supporting test programs from their inception to their receipt of test data were traced. The process of random arrival of tests (probabilistic demand), the complexity of the scheduling process and the character of heuristicallly derived scheduling decisions were described. The necessity for eliminating a large number of combinations and permutations of equipments required versus available to reduce the scheduling model to manageable proportions within restraints imposed was justified. The pilot model was conceived in final form to contain all practical considerations and approximations of heuristic judgments was generally described. The adaptability of the model and its potential value in gaming exercises to determine the optimum man-machine combination for scheduling processes were discussed.

Chapter III has as its main theme the importance of psychological rapport between schedulers and the researcher when engaged for the purpose of modeling heuristically based scheduling operations. The need for intimate involvement of the researcher in range scheduling operations was initially discussed. The necessity for special secluded session with schedulers to explore the network of factors making up the heuristic environment in which they operate was identified. The use of apparently contradictory scheduling decisions as the basis for the probing question quasi-psychiatric technique employed to extract heuristic factors from schedulers' minds was developed. The follow-on development of logic flow diagrams approximating the pattern of heuristic considerations used by schedulers was discussed.

Implications of this experience and findings concerning the modeling of scheduling operations in general resulting from search of the literature were then integrated and presented as procedures useful to operations researchers. Finally, some cursory observations were made concerning the transition of operations researchers from student to professional status.

In Chapter IV major factors underlying the heretofore "shadow" priorities system at play in the scheduling process were identified and reassembled in the form of an algorithm. The Scheduling Request Working Form for scheduling officers, designed to include priority entries from the algorithm and other data essential to the machine scheduling program, was presented. The follow-on step of converting test request line entry data to cards (tapes) as the basic input to the scheduling model was noted. Over-all development of the computer scheduling model from logic flow diagram to machine program was described. The ability of the computer scheduling program to print-out a weekly schedule for a typical week was demonstrated. That this print-out was in different format but identical in content with the weekly schedule developed by scheduling officers, with the exception of design differences intended, was noted.

In Chapter V, it was initially concluded that a major contribution of the research effort was to demonstrate that computer scheduling of missile and spacecraft launch and support tests in a heuristic environment was possible. Immediate uses of the pilot scheduling model were identified. It was concluded, however, that its most significant value was its potential for determining the optimum man-machine combination on a sound cost/effectiveness basis at each evolutionary step in its larger development and application to the over-all range scheduling problem. Translational steps for evolutionary development were given. The increased discipline which computer usage by its very nature will impose on scheduling processes was discussed.

Conclusions

1. The ability of the pilot scheduling model to print out a typical week's schedule has been demonstrated.
2. The conclusions of qualified scheduling officers is that the model more than satisfies early expectations; that there is a

man-machine combination which will materially aid their scheduling process; therefore, that the hypothesis has been validated with degree only remaining to be determined by evolutionary growth of the pilot model as described and phased cost/effectiveness analysis.

3. The scheduling model in evolutionary phases has the potential for many applications other than purely as a weekly scheduling aid. One of these is to concentrate and foreshorten the period of training of scheduling officers. Another is to accumulate and evaluate statistics from the "clock" file concerning the utilization of equipment inventories. A third use related to the second, is the use of the model to investigate future inventories of equipments required to satisfy projected test loads. A fourth is its application in real time scheduling (rescheduling) on a daily or other time unit or event basis.

4. Much more scheduling capability and finesse has been built into the model than required to satisfy the demands for scheduling the typical week's test request load, e.g., the capability of accepting and scheduling up to three launch tests in any one day, testing for latitude to slip or advance T-times based on

"window" tolerances, and slipping or advancing them out of conflict while staying within range operating hours or minimizing overtime.

5. Important contributions to the body of applied science have been made.

Proposals for Further Study

1. These have been discussed throughout the several preceding chapters, but in particular Chapter V.

A SELECTED BIBLIOGRAPHY

1. Ackoff, Russell L. Progress in Operations Research. Volume I. New York, N. Y.: John Wiley and Sons, Inc., 1961.

2. Sasieni, M., A. Yaspan, and L. Friedman. Operations Research -- Methods and Problems. New York, N. Y.: John Wiley and Sons, Inc., 1959.

3. Broome, P., and W. Conner. "Prediction of Launch Statistics for FY 63-76 Under a Poisson Assumption," Pan American World Airways, Inc., Air Force Missile Test Center, Patrick Air Force Base, Florida, 1962.

4. Neilson, W. A., T. A. Knott, and P. W. Carhart. Websters New International Dictionary of the English Language. Second Edition. Springfield, Massachusetts: G. and C. Merriam Co., 1951.

5. Hutchinson, C. E. "Heuristic Procedures in Problem Solving," Office of Aerospace Research, No. 17, (5 November 1962), pp. 1-2.

6. Schaeffer, K. H. "The Logic of an Approach to the Analysis of Complex Stystems," Stanford Research Institute, SRI Project No. IMU-3546, Air Force Technical Report AFOSR-2136, 1962.

7. Miles, Herman W. "Operations Research -- An ASTIA Report Bibliography." Armed Services Technical Information Agency, January, 1962.

8. Churchman, C. W., R. L. Ackoff, and E. L. Arnoff. Introduction to Operations Research, New York, N. Y.: John Wiley and Sons, Inc., 1960.

9. Luck, T. P., and J. W. Tiettmeyer. "OASIS Operating Procedure (Immediate System)," Land-Air, Inc., Technical Report No. 17, June, 1960.

10. Pacific Missile Range, Range Operations Department, Test Data Division, "Evaluation, Status, and Anticipated Development of OASIS," (undated).

11. Mentioned -- proprietary rights precludes further identification.

12. Frisbie, R. J., L. A. Leake, and C. E. Wisler. "On the Use of Computers in the Range Scheduling Process," Operations Research Group, Pacific Missile Range, Point Mugu, California, Informal Note 01-2/4-63, 1963.

13. Commander, AFMTC, (MTORC), Patrick AFB, Florida. "AFMTC Range Communications Instructions," October, 1963.

14. Association for Computing Machinery, Baltimore, Md., "Communications of the Association for Computing Machinery," Vol. 2, No. 7, July, 1959.

15. Stillson, Paul. "Implementation of Problems in O.R.," Operations Research, Vol. 11, Number 1, (January-February, 1963), pp. 140-147.

16. Commander, Air Force Missile Test Center (MTORR), Patrick Air Force Base, Florida. "Index to AFMTC Test Documentation," November, 1963.

17. Operations Directives Library. OD's 001 Through 4499, Deputy for Operations, AFMTC, Patrick Air Force Base, Florida, (current series).

18. Deputy Chief of Staff, Plans and Programs, AFMTC, Patrick Air Force Base. "Range User's Handbook," 1962.

19. ASTIA Abstracts from Operations Research -- A Report Bibliography, 1962.

    a. Johnson, S. R. "Problem," (Research Memo. No. RM-2398), RAND, November, 1959.

    b. Thompson, G. L. "Recent Developments on the Job Shop Scheduling Problem," Carnegie Inst. of Tech. Graduate School of Industrial Administration, Pittsburgh, Pa., Research Memo. 69, May, 1960.

    c. Fischer, Henry, and Gerald Thompson. "Probabilistic Learning Combinations of Local Job Shop Scheduling Rules," Carnegie Inst. of Tech., Pittsburgh, Pa., (ONR Research Memo. No. 80) February, 1961.

19. (Continued)

d. Manne, Alan S. "On the Job Shop Scheduling Problem," Cowles Foundation for Research in Economics, Yale U., New Haven, Conn., (Cowles Foundation Discussion Paper No. 73), May, 1959.

e. Modigliani, Franco, and Herbert A. Simon. "On the Relation Between a Heuristic and an Exact Production Decision Rule," Carnegie Inst. of Tech. Graduate School of Industrial Administration, Pittsburgh, Pa., Research Memo. No. 17, June, 1954.

f. Manne, A. S. "Costs and Benefits in Mathematical Programming," RAND Corp, Santa Monica, Calif., Report No. RM-1785, August, 1956.

g. Adjutant General's Office, Washington, D. C. "Computers for Management," Special Bibliography No. 1, March, 1956.

h. Gere, W. S., Jr. "Heuristics in Job Shop Scheduling," Carnegie Inst. of Tech. Graduate School of Industrial Admin., Pittsburgh, Pa., Research Memo. No. 70, June, 1960.

i. Phillips, C. A. "Automatic Data Processing in Management Operations of the Department of Defense," Industrial College of the Armed Forces, Washington, D. C., (Pub. No. L58-96), January, 1958.

20. McCormick, Ernest J. Human Engineering. (Motivation of Subjects, page 15), New York, N. Y.: McGraw-Hill Book Company, Inc., 1957.

21. Wilson, E. Bright, Jr. An Introduction to Scientific Research. New York, N. Y.: McGraw-Hill Book Company, Inc., 1952.

22. Fansler, Thomas. Creative Power Through Discussion. New York, N. Y.: Harper and Brothers, 1950.

APPENDIX A

THE ORIGINAL PROPOSAL FOR RESEARCH

MEMO ROUTING SLIP — *NEVER USE FOR APPROVALS, DISAPPROVALS, CONCURRENCES, OR SIMILAR ACTIONS*

TO	INITIALS / DATE	ACTION
1 MTORP-1 Maj Peckham		CIRCULATE / COORDINATION
2		FILE / INFORMATION
3		NOTE AND RETURN / PER CONVERSATION
4		SEE ME / SIGNATURE

REMARKS

Ref attached letter 17 Apr 63 fm MTGS to MTGSO "Study of Computer Applications" with Proposal for Ph.D Research and Thesis Subj: On Optimizing Scheduling of Missile and Space Vehicle Testing and Operations.

It appears reasonable that application of memory banks and computer processes to the scheduling procedure could be used effectively to reduce work load and increase the accuracy of scheduling processes.

This might be a desirable subject for investigation by competent Operational Analysis personnel.

Return attached materials with your comments.

FROM P.A.TISDALE, LtCol,USAF MTORP

DATE 7 Aug 63

PHONE UL7-7333

DD FORM 1 OCT 60 95 Replaces DD Form 94, 1 Feb 50 and DD Form 95, 1 Feb 50 which will be used until exhausted. ☆ GPO: 1960—0—568294

MEMO ROUTING SLIP — *NEVER USE FOR APPROVALS, DISAPPROVALS, CONCURRENCES, OR SIMILAR ACTIONS*

TO	INITIALS / DATE	ACTION
1 MTORP L/C Tisdale		CIRCULATE / COORDINATION
2		FILE / INFORMATION
3		NOTE AND RETURN / PER CONVERSATION
4		SEE ME / SIGNATURE

REMARKS

1. Appreciate your forwarding the attached for comment.

2. Many studies & restudies have been made re computerized scheduling & memory devices; however in the past, very little has come of the studies except recognition that range scheduling is a rather difficult job requiring a particular type individual.

3. PMR has made several in-house and contracted studies and arrived at the same conclusion. They do use a "computer" that really does not compute anything - it provides automatic printout

FROM MTORP-1 [signature] Peckham

DATE 8 Aug 63

PHONE Hotline

DD FORM 1 OCT 60 95 Replaces DD Form 94, 1 Feb 50 and DD Form 95, 1 Feb 50 which will be used until exhausted. ☆ GPO: 1960—0—568294

MEMO ROUTING SLIP — *NEVER USE FOR APPROVALS, DISAPPROVALS, CONCURRENCES, OR SIMILAR ACTIONS*

	INITIALS	ACTION
1 TO		CIRCULATE
	DATE	COORDINATION
2		FILE
		INFORMATION
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		PER CONVERSATION
4		SEE ME
		SIGNATURE

REMARKS

of the schedule daily and does cut a tape for transmission of their schedule to D/E stations. It requires a rather extensive admin procedure to prepare cards, take them nightly to the computer, & pick up scheds the following morning.

4. I am not convinced that the money involved in setting up a memory storage device as proposed would ~~not~~ be worth the expenditure; however, I am no slave to tradition (!) and if Dr Hess & Mr Fennema believe that it is worth the time to investigate further, I will cooperate

FROM	DATE
	PHONE

DD 1 OCT 60 FORM 95 — Replaces DD Form 94, 1 Feb 50 and DD Form 95, 1 Feb 50 which will be used until exhausted. ☆ GPO: 1960—0—568294

MEMO ROUTING SLIP — *NEVER USE FOR APPROVALS, DISAPPROVALS, CONCURRENCES, OR SIMILAR ACTIONS*

	INITIALS	ACTION
1 TO		CIRCULATE
	DATE	COORDINATION
2		FILE
		INFORMATION
3		NOTE AND RETURN
		PER CONVERSATION
4		SEE ME
		SIGNATURE

REMARKS

to the maximum extent.*

5. If money is available to play with, it would be much better spent on tools we really need, ie, a first class closed circuit TV system ——

* It would seem that the time and effort req'd to keep a computer/storage device current, plus req't to punch cards, etc, for operation, would be cumbersome.

FROM MTORP-1	DATE
RKP	PHONE

DD 1 OCT 60 FORM 95 — Replaces DD Form 94, 1 Feb 50 and DD Form 95, 1 Feb 50 which will be used until exhausted. ☆ GPO: 1960—0—568294

OKLAHOMA STATE UNIVERSITY

PROPOSAL FOR Ph. D. RESEARCH AND THESIS

SUBJECT: ON OPTIMIZING SCHEDULING OF MISSILE AND SPACE VEHICLE TESTING AND OPERATIONS

28 April 1963

FREDERICK F. FENNEMA

FOREWORD

Most of the large size missiles and space vehicles are launched and controlled from Cape Canaveral, Florida. Testing of vehicles from the time they arrive on the Cape varies from checkout of vehicle components and systems gradually integrated culminating in full scale dry runs and ultimately live launches. The staff unit responsible for scheduling all tests and associated measurement and control equipments is an organizational element of the Air Force Missile Test Center (AFMTC). The Commander, AFMTC, is the executive agent for the Department of Defense. He is responsible for developing, equipping and operating the Atlantic Missile Range (AMR) to best serve the testing needs of Range users: The National Aeronautics and Space Administration, the U. S. Air Force, U. S. Navy, and U. S. Army.

It is the scheduling problem involving many range users, many programs, the variety of missile and space vehicles involved, their particular requirements for instrumentation and measurement systems distributed spatially and in time, to which this proposal is addressed.

INTRODUCTION

Under actual circumstances, missile and space vehicles and, therefore, requests for support and live launch tests tend to "arrive" at random from the body of programs active on the AMR. Such requested tests are arranged in weekly scheduling meetings considering program priority, availability of test support resources specified in the Operational Directive for each program, and other criteria.

Each Operational Directive, one per program, may consist of several volumes listing in exacting detail individual test measurement requirements for both support and launch tests. AMR scheduling effectiveness under such dynamic circumstances depends on: (1) experienced individuals having thorough familiarity with OD test specifications, (several feet of documentation in mental storage), (2) knowledge of the critical response time for range set-up of instrumentation and measurement system arrays tailored to each test requirement, (3) knowledge of non-interference testing which may proceed simultaneously, (4) the relative essentiality of measurement equipments to any given test on which basis the test originator may or may not wish to proceed, etc.

The effectiveness of such scheduling (and operation) impinges at present, therefore, almost totally on human intelligence and experience. No reliable means for pre-selection of individuals having scheduling aptitude are known. The training period is extensive -- estimated to be from three to five years. The stakes associated with scheduling decisions are high from any point of view. There have been a plethora of "black box" and "automation by computer" suggestions but none backed up by sufficient research to relate economy reliability and responsiveness of scheduling systems along a continuum from the way this complex operation is performed now to the way it theoretically may be with primary dependence on modeling and computer technology.

PROPOSITION

It is hypothesized that there is a combination of human intelligence and computer application which may be assembled for most efficient handling of the range scheduling problem. The research would involve the modeling of the operation the way it is done now, the potentiality for mechanizing information storage and retrieval frequently in a rapid state of revision, and the evolving and testing of several mixes of human and machine decision making processes relative to the problem. Proper appreciation would be taken of any approaching limitation of the continued absolute dependence on human intelligence to satisfy an increasingly complex function. Conversely, decreasing elasticity in judgment and adaption, which increasing computer automation by its very nature could cause, would be of significant concern.

A sub-objective may very well emerge: That a model of scheduling operations computerized to a degree may be used in gaming exercises to foreshorten the training of schedulers and actually extend their quality and capacity for their human decision making. Research concerning scheduling modeling and an optimum man-machine system may provide a reliable means through simulation for estimating inventories of instrumentation, equipment and facilities for future time periods given the projected testing load or vice versa. Also, it is expected the research and modeling will be sufficiently fundamental to be applicable in a wide range of scheduling situations other than missile tests -- where resources to be expanded are costly and adaptability to changing circumstances is of primary significance.

APPENDIX B

ORIGINAL DETAILED LOGIC FLOW DIAGRAMS OF THE WEEKLY SCHEDULING FUNCTION

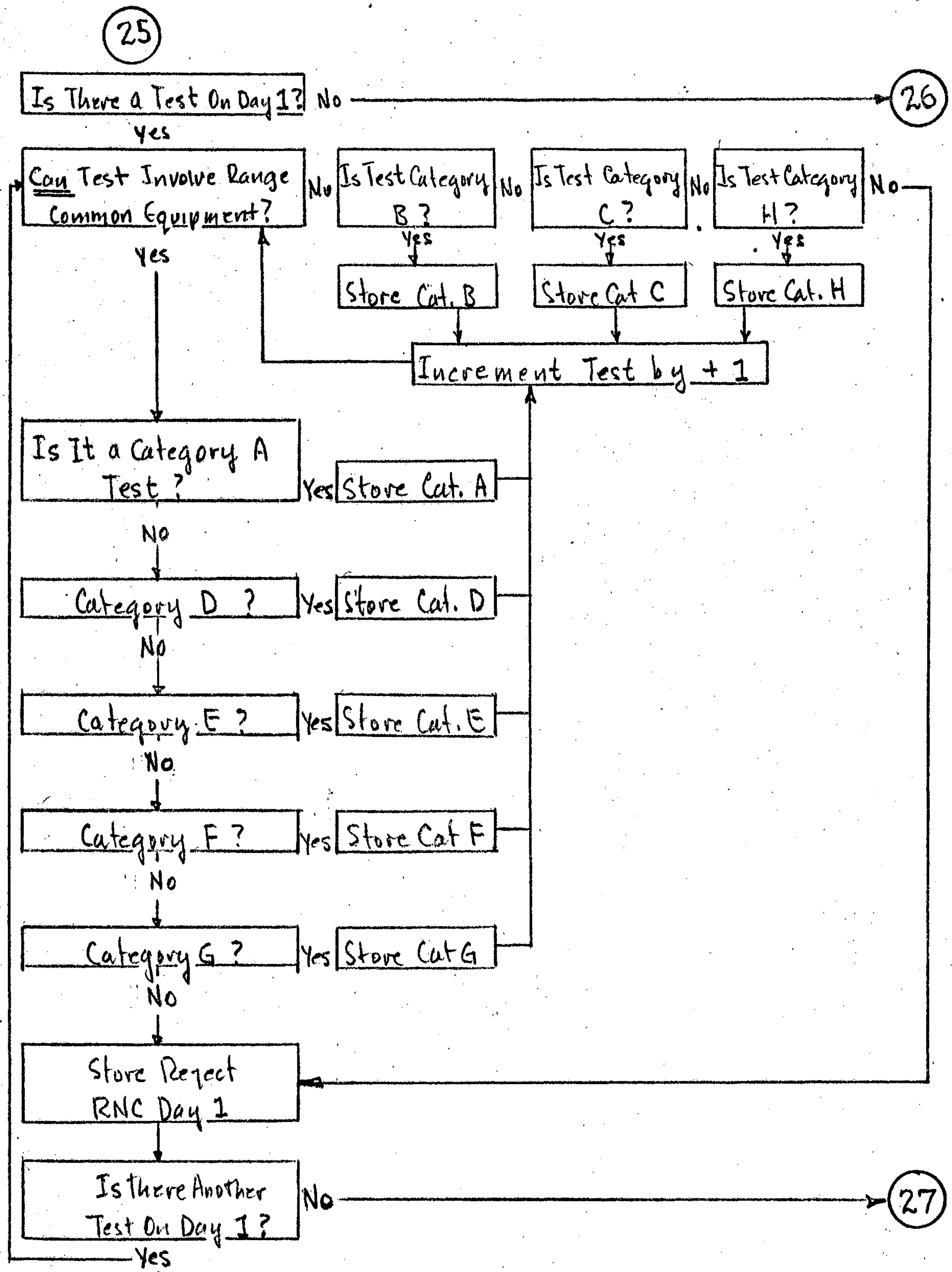


Figure 20. Flow Diagram, Sort of Test Requests Into Categories

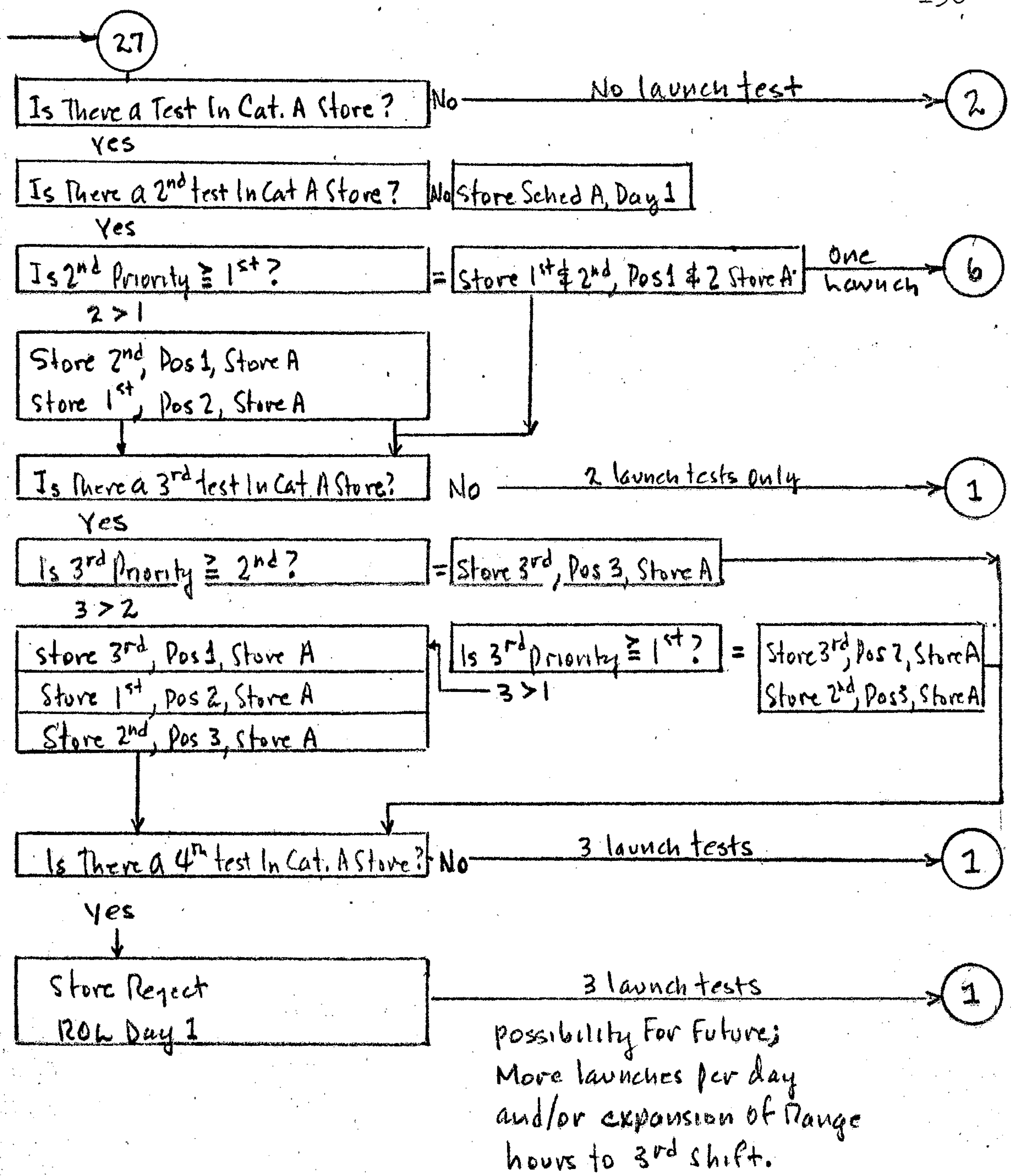


Figure 21. Flow Diagram, Ordering of Category A, Launch Tests, by Priority

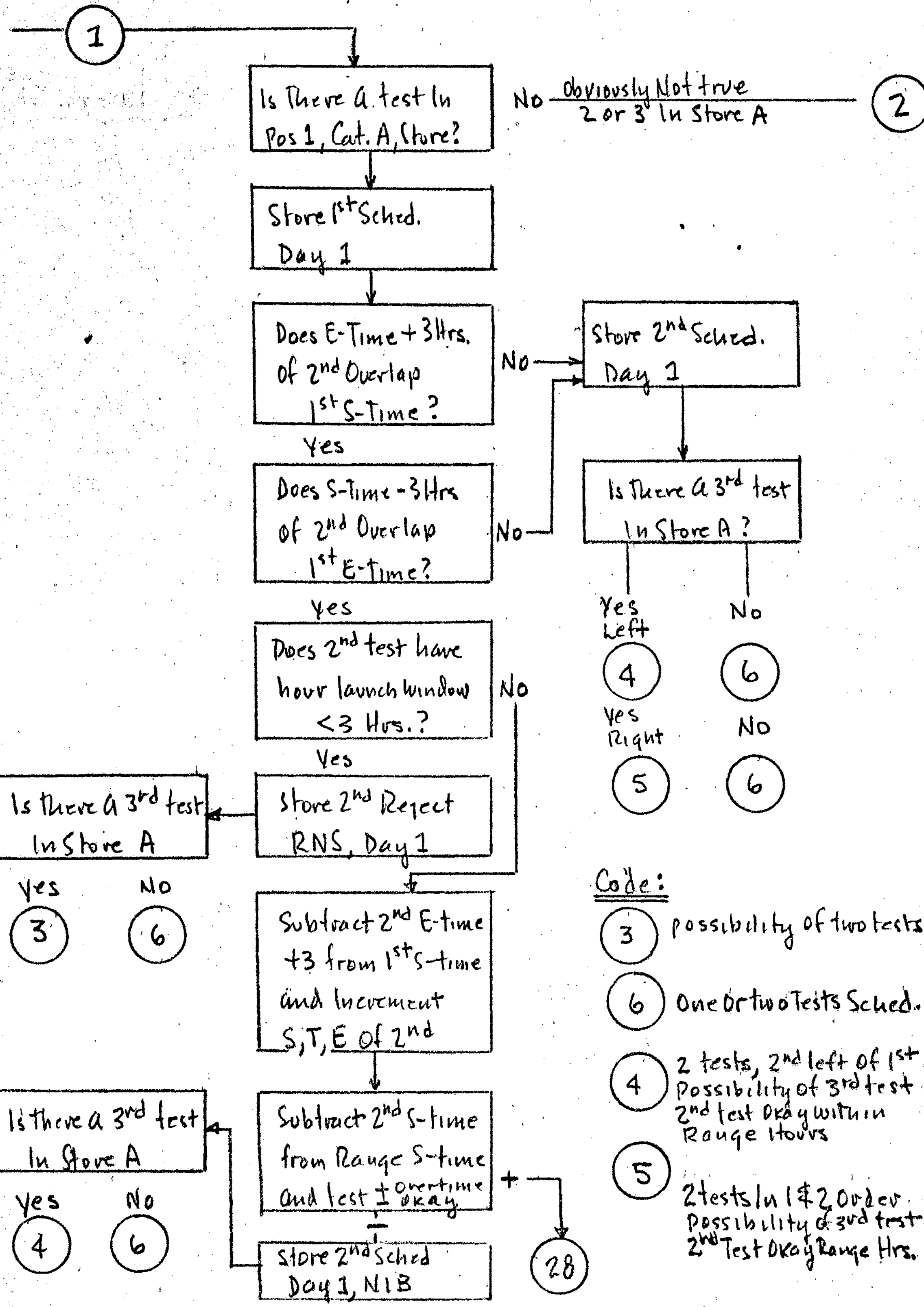


Figure 22. Flow Diagram, Scheduling Category A, Launch Tests, Shift to Avoid Conflicts and Minimizing Range Overtime

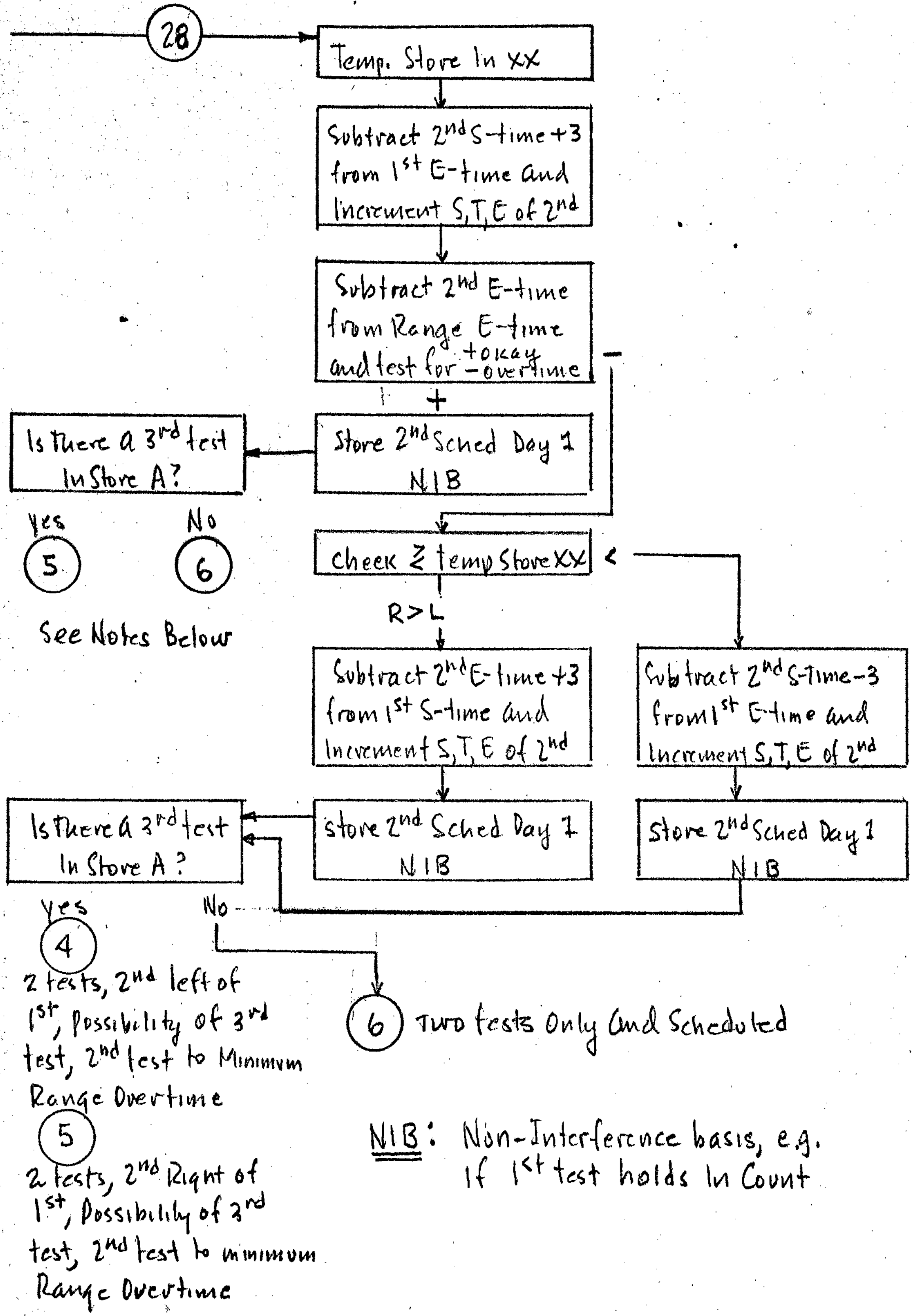


Figure 22 continued

(3) Case of reject 2nd test so routine (1) repeated using terminology 3rd relative to 1st in place of 2nd relative to 1st. Final logic boxes go out to (6), Figure 23.

Similarly, logic flow for (4), the case of 2nd test stored Sched Day 1 Left and (5), the case of 2nd test stored Sched Day 1 Right emerge at (6), Figure 23

1, 2, or 3 launch tests have been scheduled at this point.

Figure 22 continued

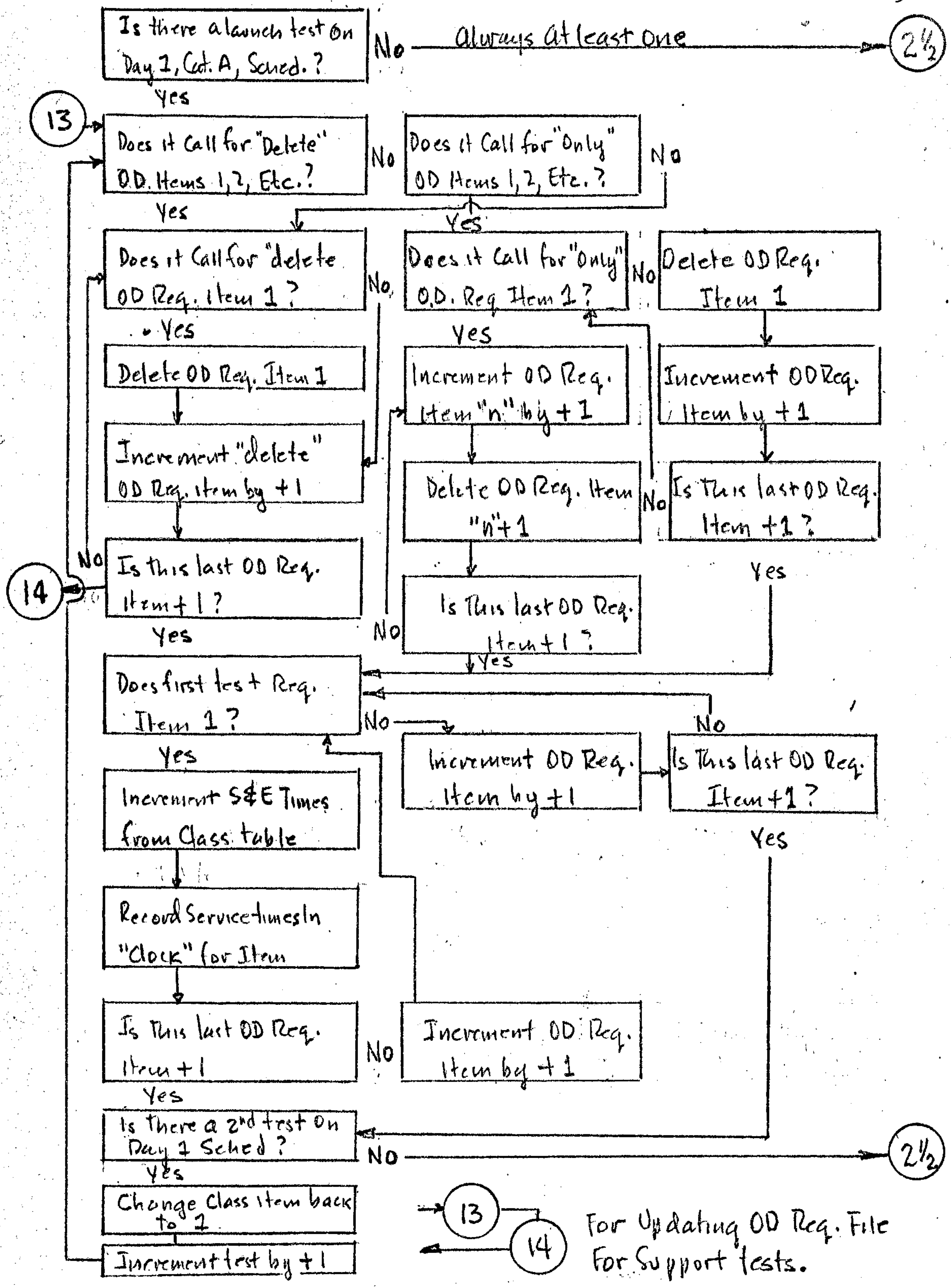


Figure 23. Flow Diagram, Up-dating OD Required File by Deletes, Launches and Support Tests

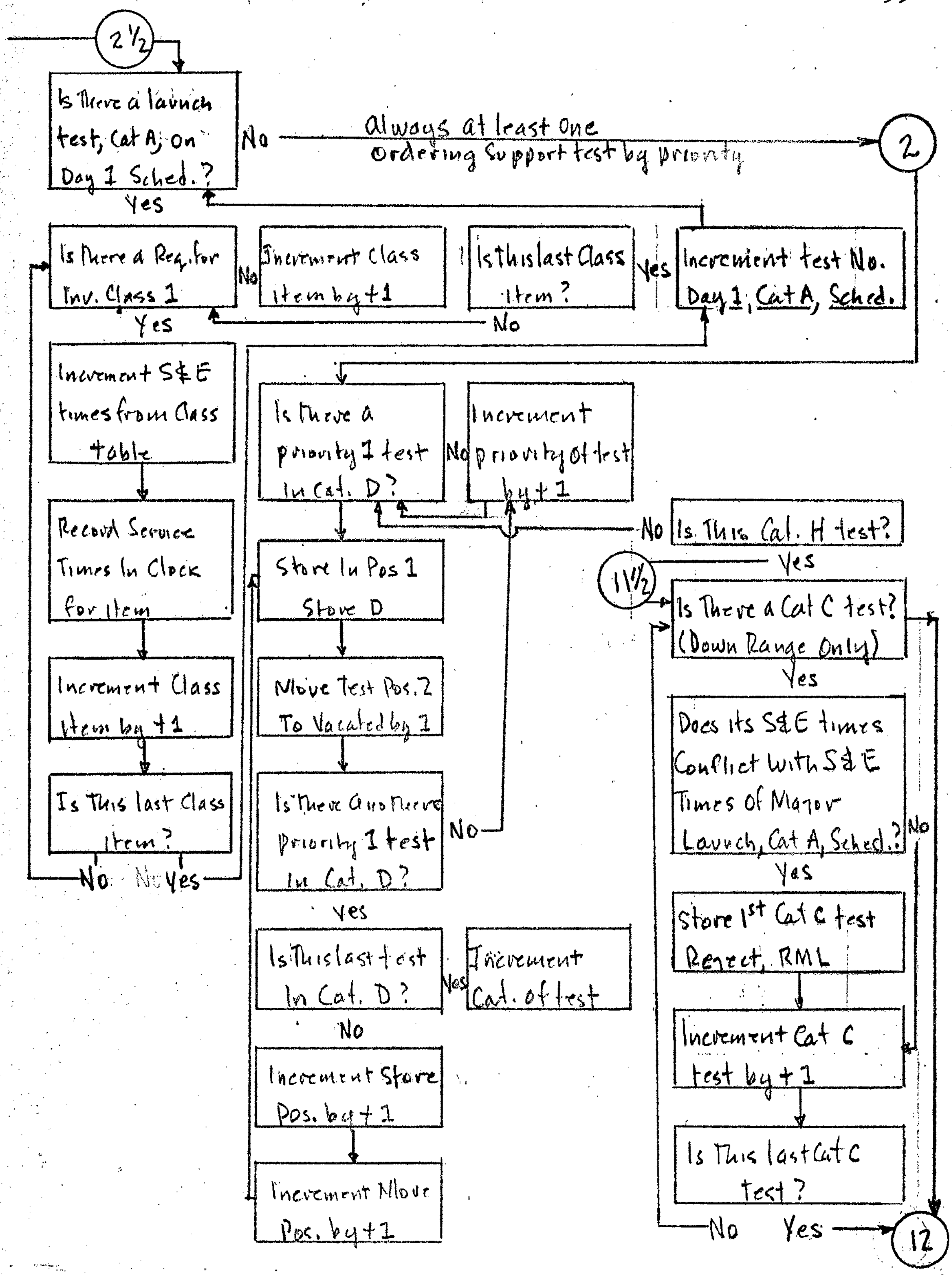


Figure 24. Flow Diagram, Up-dating "Clock" File with Launch OD Requirements; Ordering Support Tests in Categories D, E, F, and G by Priorities; Check/Reject Category C (Down Range Only) Tests for Conflict with Category A, Launch, Tests

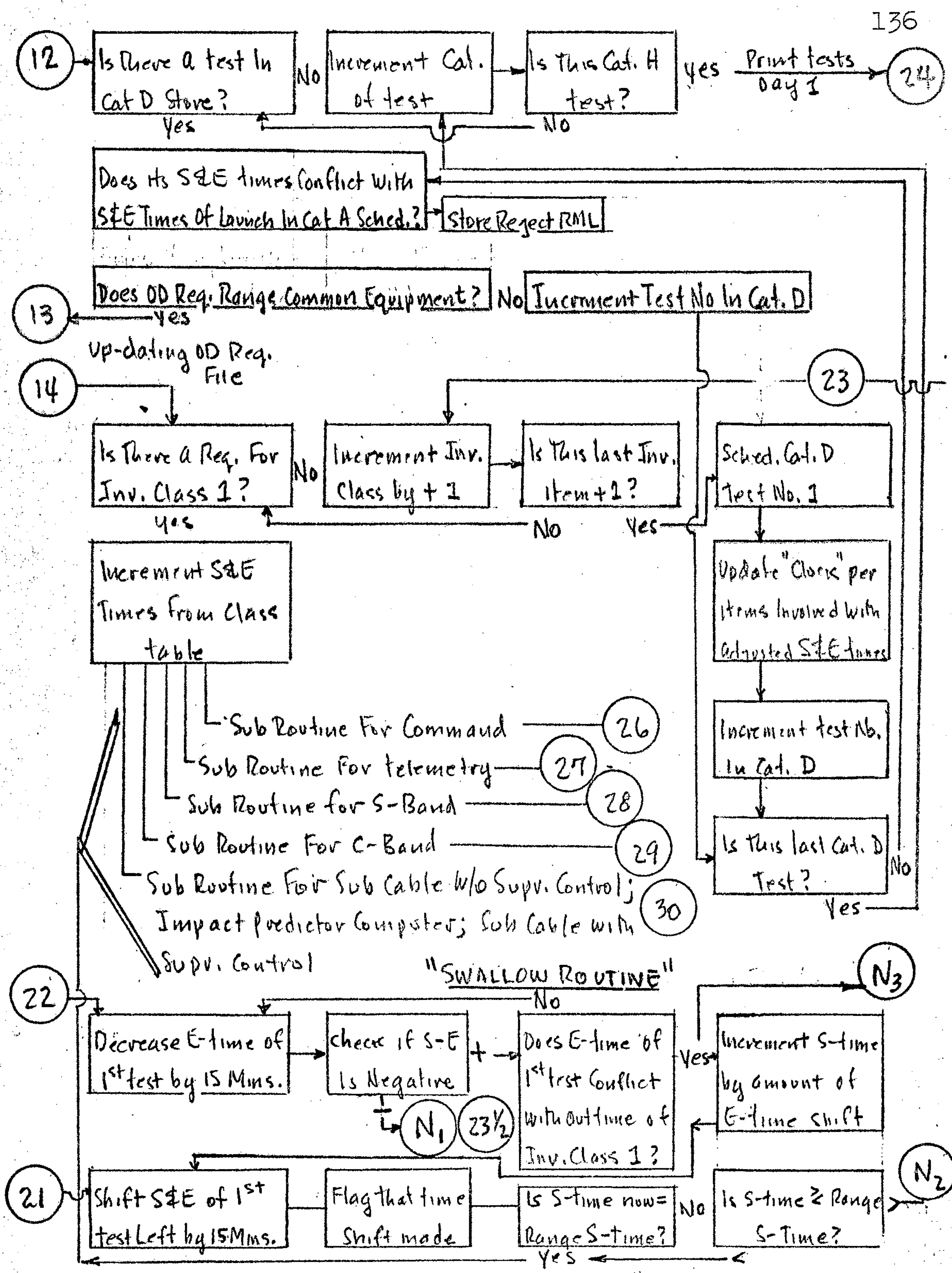


Figure 25. Flow Diagram, Scheduling Category D, E, F, and G, Support Tests, Gross Shift and Back-up to Avoid Conflicts, No Range Overtime, Reject as Appropriate; Irresolvable Conflict (RIC), Command Frequency Conflict (RCF), Telemetry Frequency Conflict (RTF)

(N1) Inventory Class 1 Out time not Swallowed by test and test okay with respect to Class 1.

(N2) Out to shift Right as left Range hours exceeded before Sufficient test time found for first test of Cat. D. (13) and (14) may be by-passed as up-dating of OD Required File Completed previously. Repeat Logic Flow Diagrams Figures 25 Thru 30 Using E-time entering at (12) and exiting at (18). Tests in Cat. D Scheduled, Clock File, as Appropriate, Updated, or, put in irresolvable Conflict, RIC. Category E, F, and G tests treated Similarly on Subsequent passes. → (24)

(N3) Outtime "Swallowed" by test and must be Shifted left to Clear

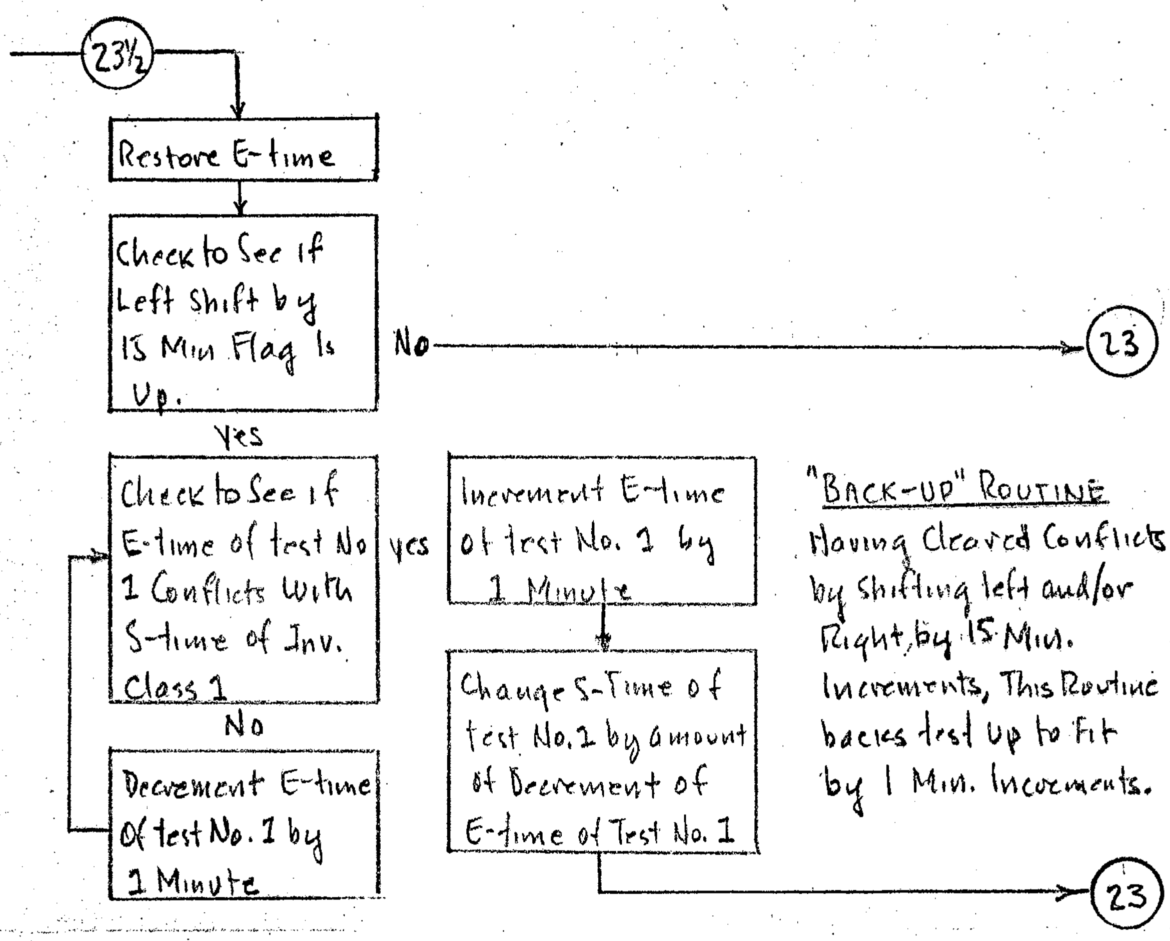


Figure 25 continued

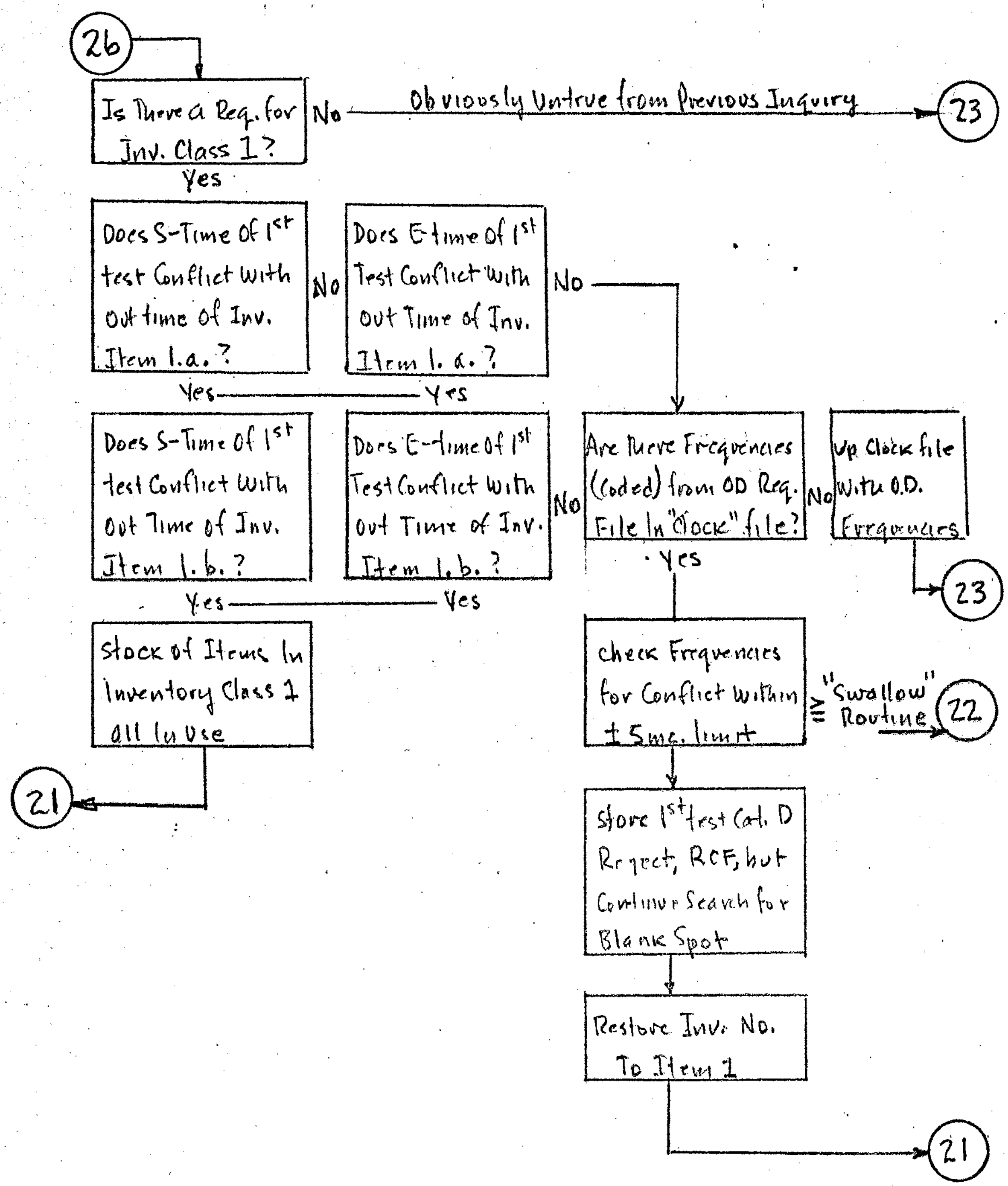


Figure 26. Flow Diagram, Sub-routine Command Class Inventory Check and Frequency Conflict Check

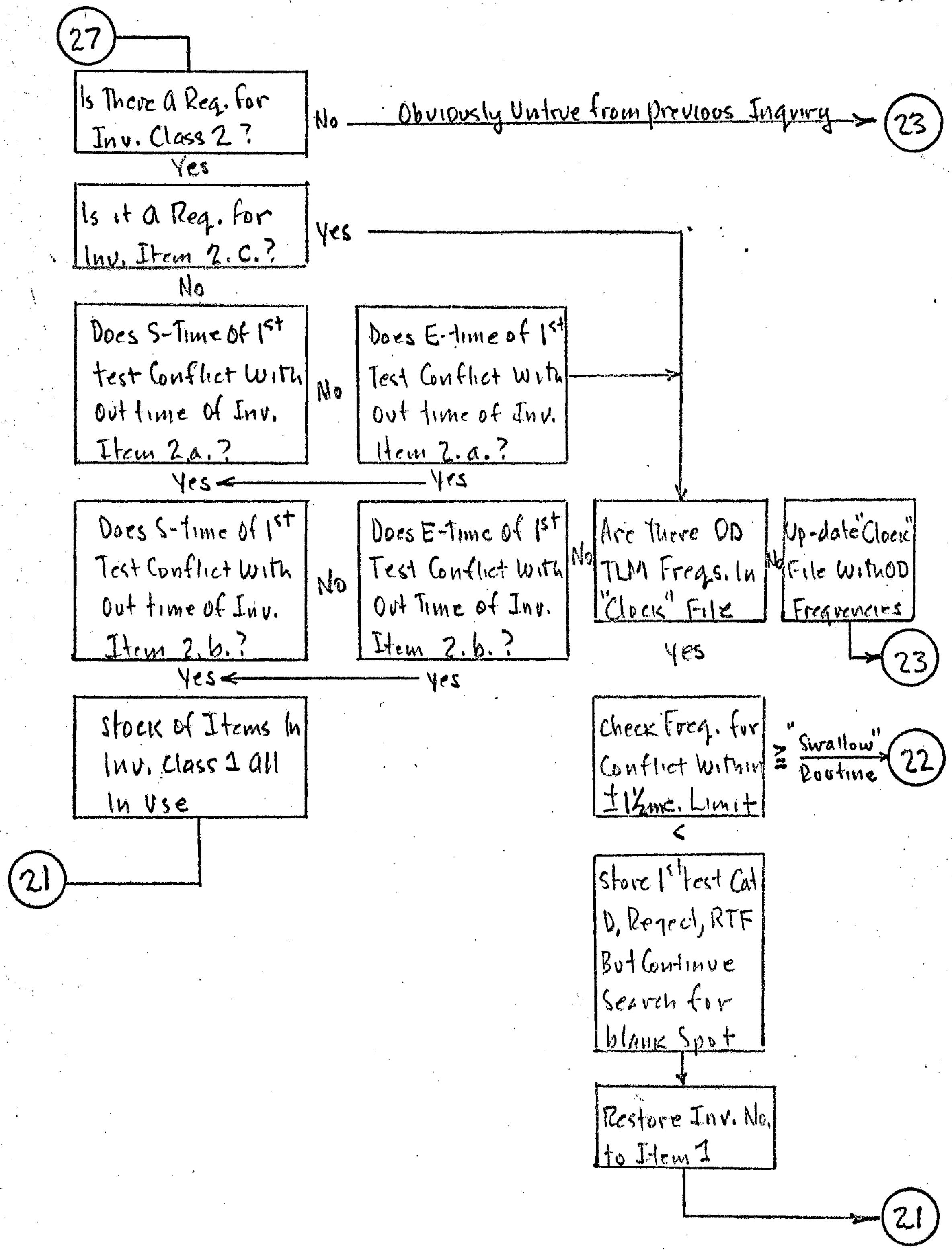


Figure 27. Flow Diagram, Sub-routine Telemetry Class Inventory Check and Frequency Conflict Check

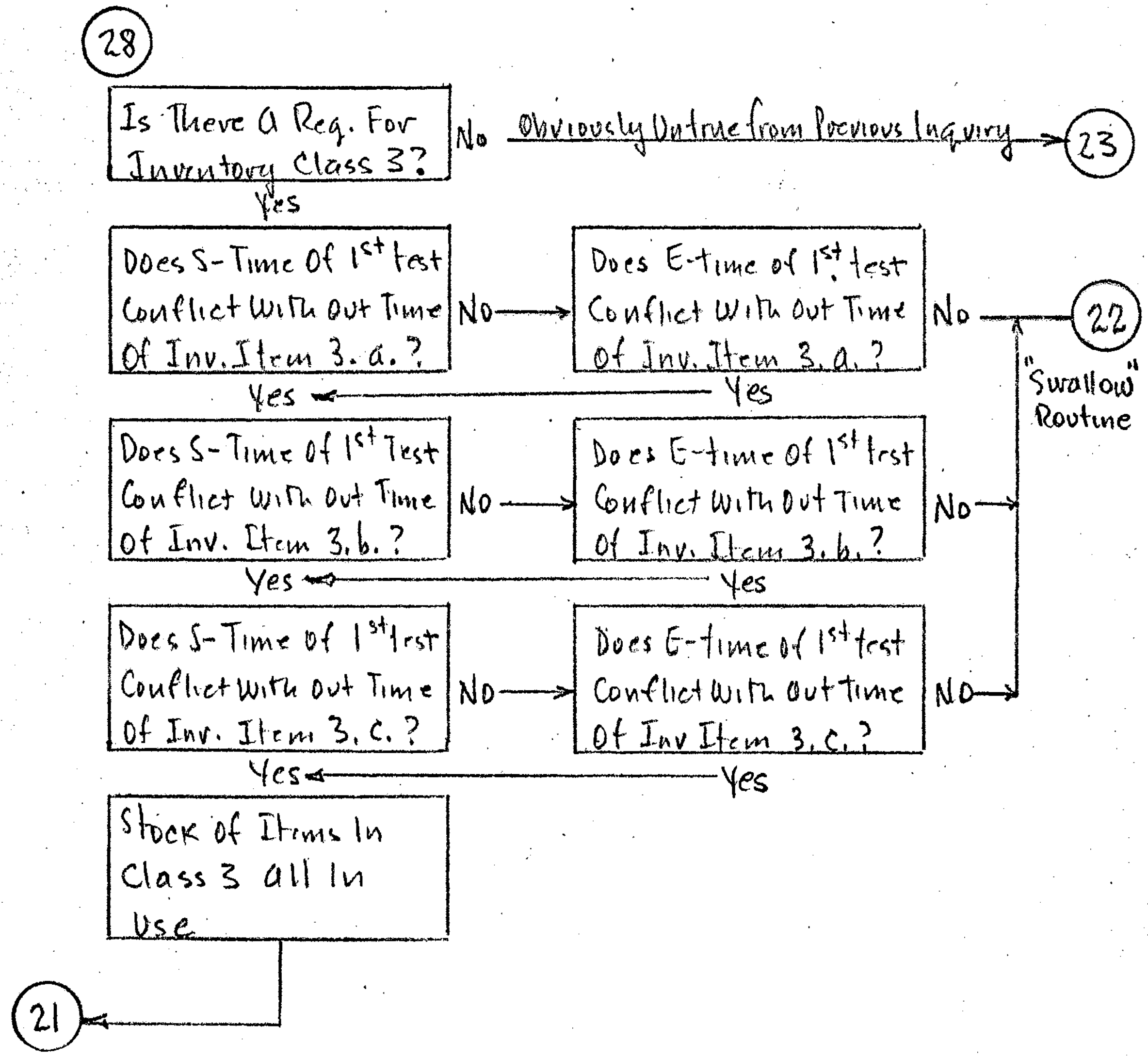


Figure 28. Flow Diagram, Sub-routine, S-Band Class Inventory Check

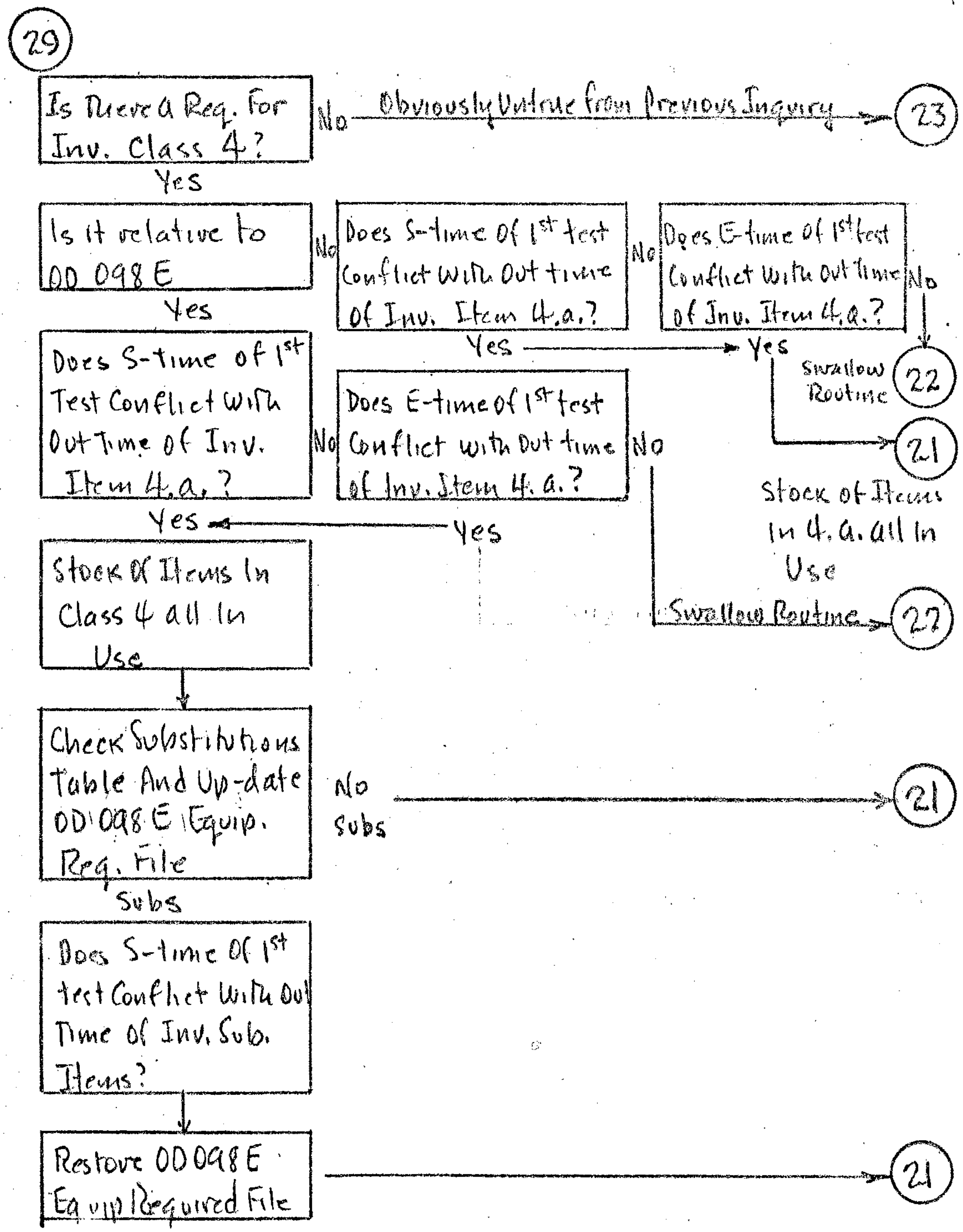


Figure 29. Flow Diagram, Sub-routine, C-Band Class Inventory Check

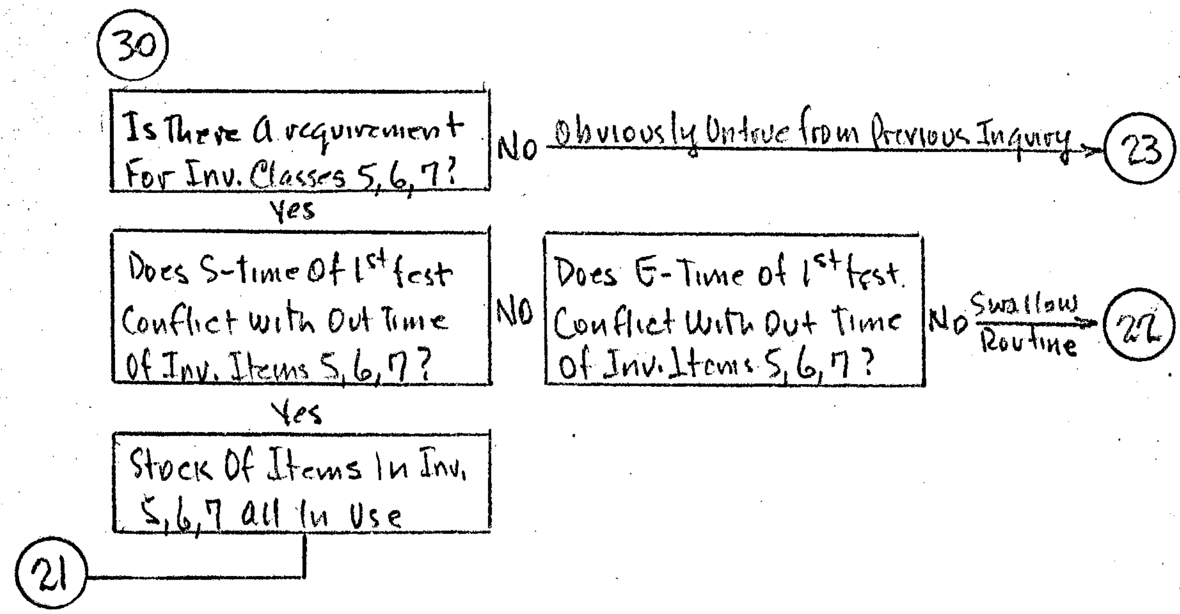


Figure 30. Flow Diagram, Sub-routine, Sub-cable w/o Supv. Control, Impact Predictor Computer, and Sub-cable with Supv. Control Classes Inventory check

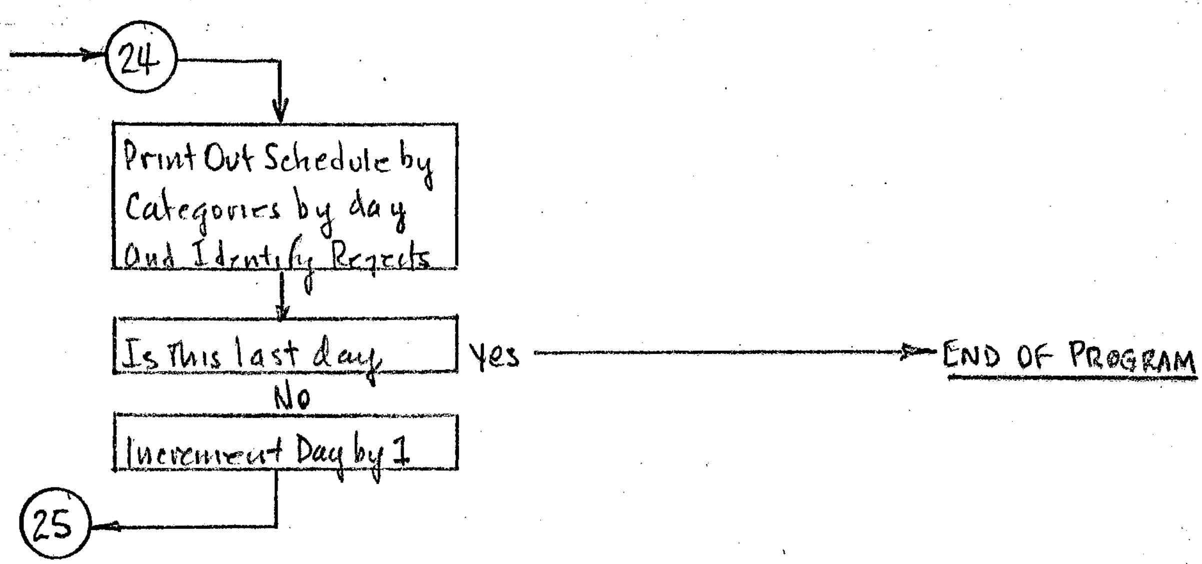


Figure 31. Flow Diagram, Print-out Schedule by Categories by Day; End of Program

APPENDIX C

COMPUTER LOGIC FLOW DIAGRAMS OF THE WEEKLY SCHEDULING FUNCTION

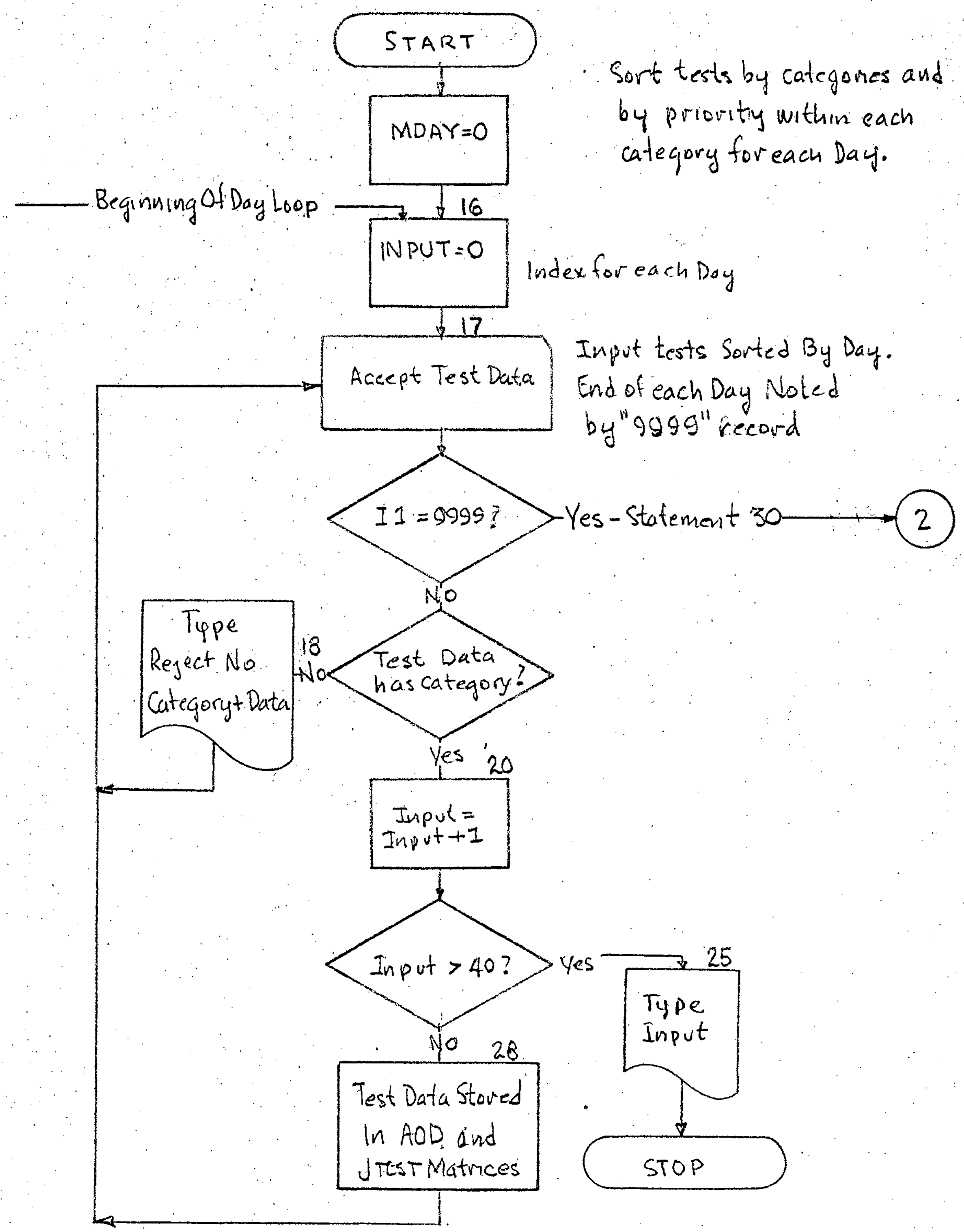


Figure 32. Machine Flow Diagram, Sort of Test Requests into Categories and Ordering by Priorities Within Categories (Pass I)

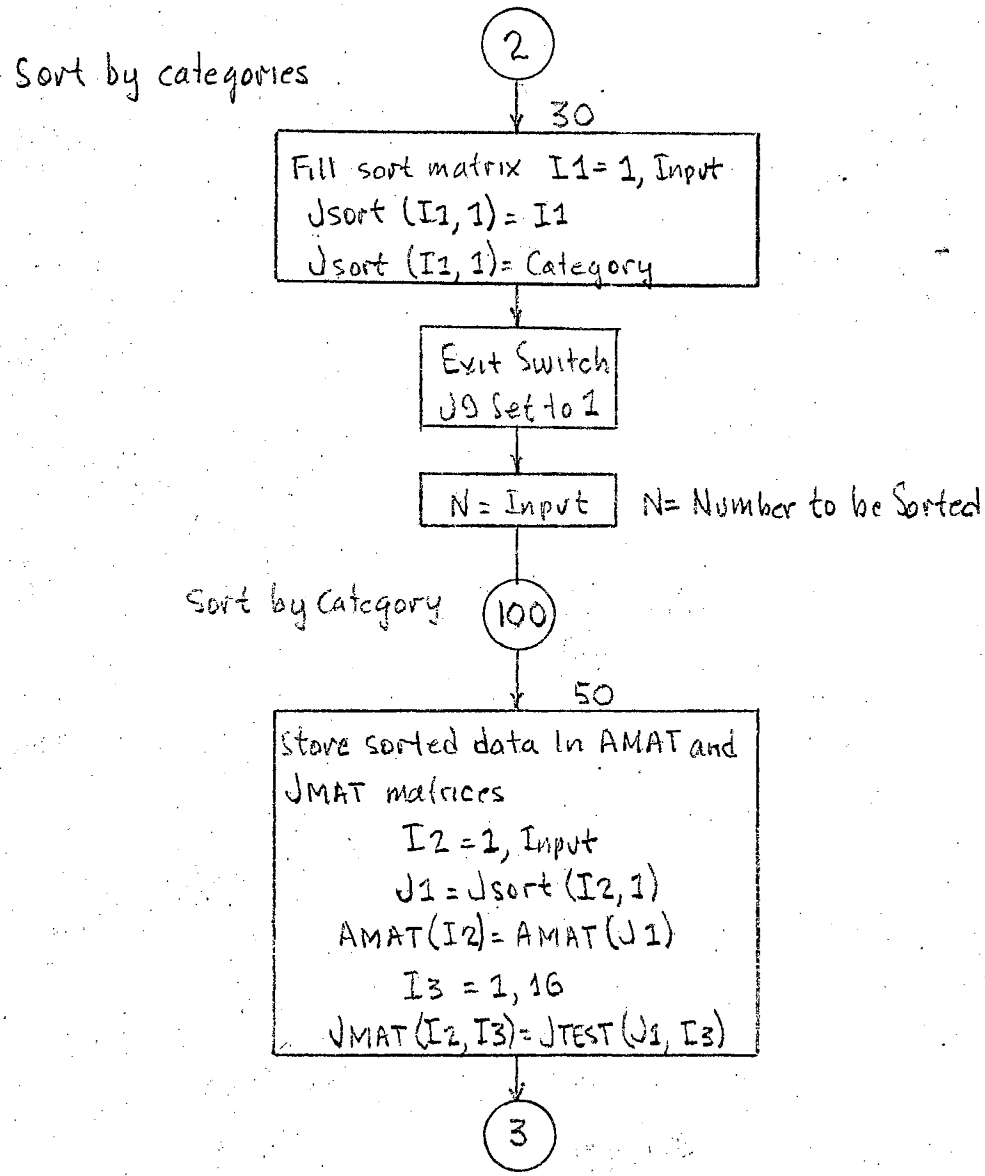


Figure 32 continued

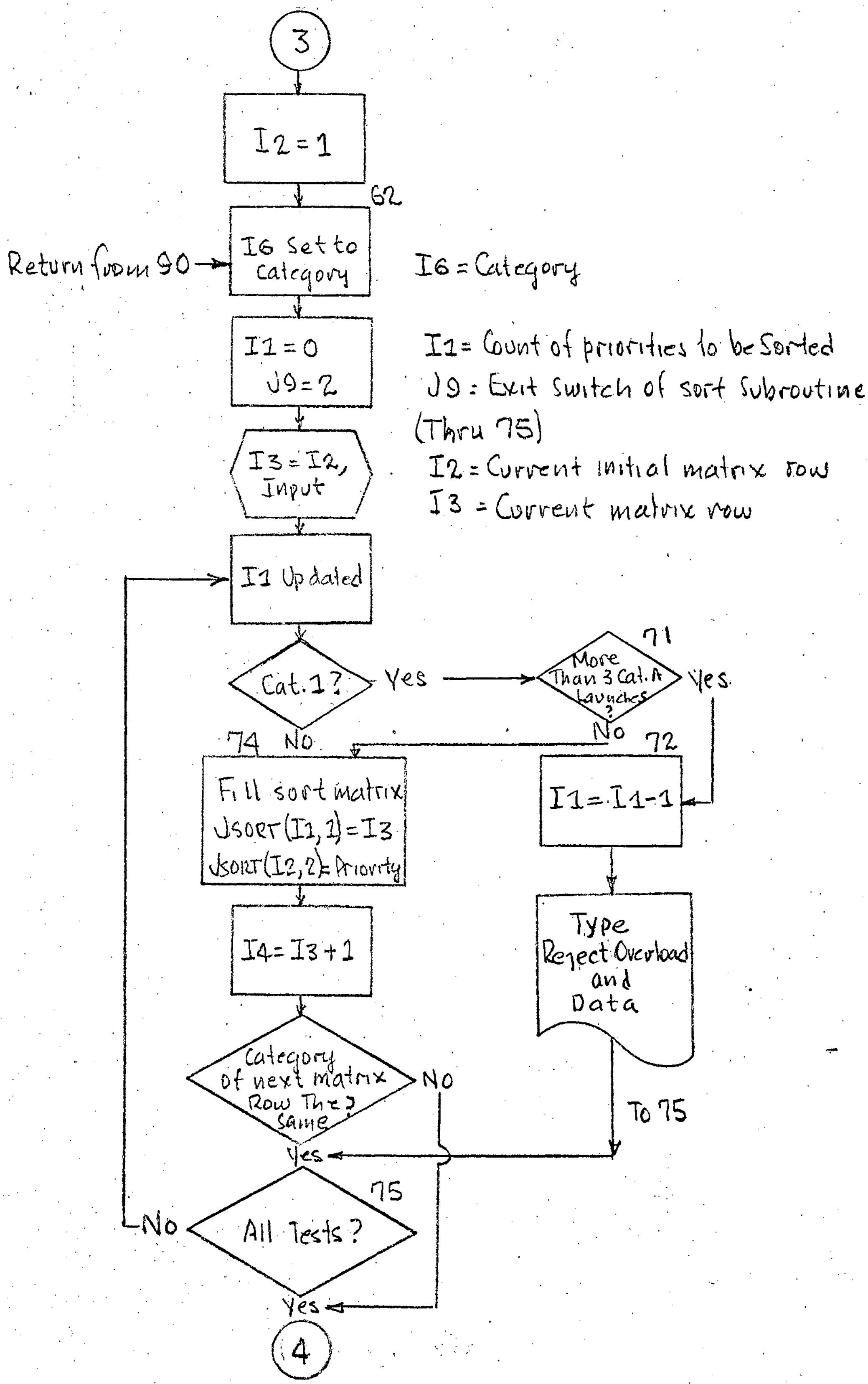


Figure 32 continued

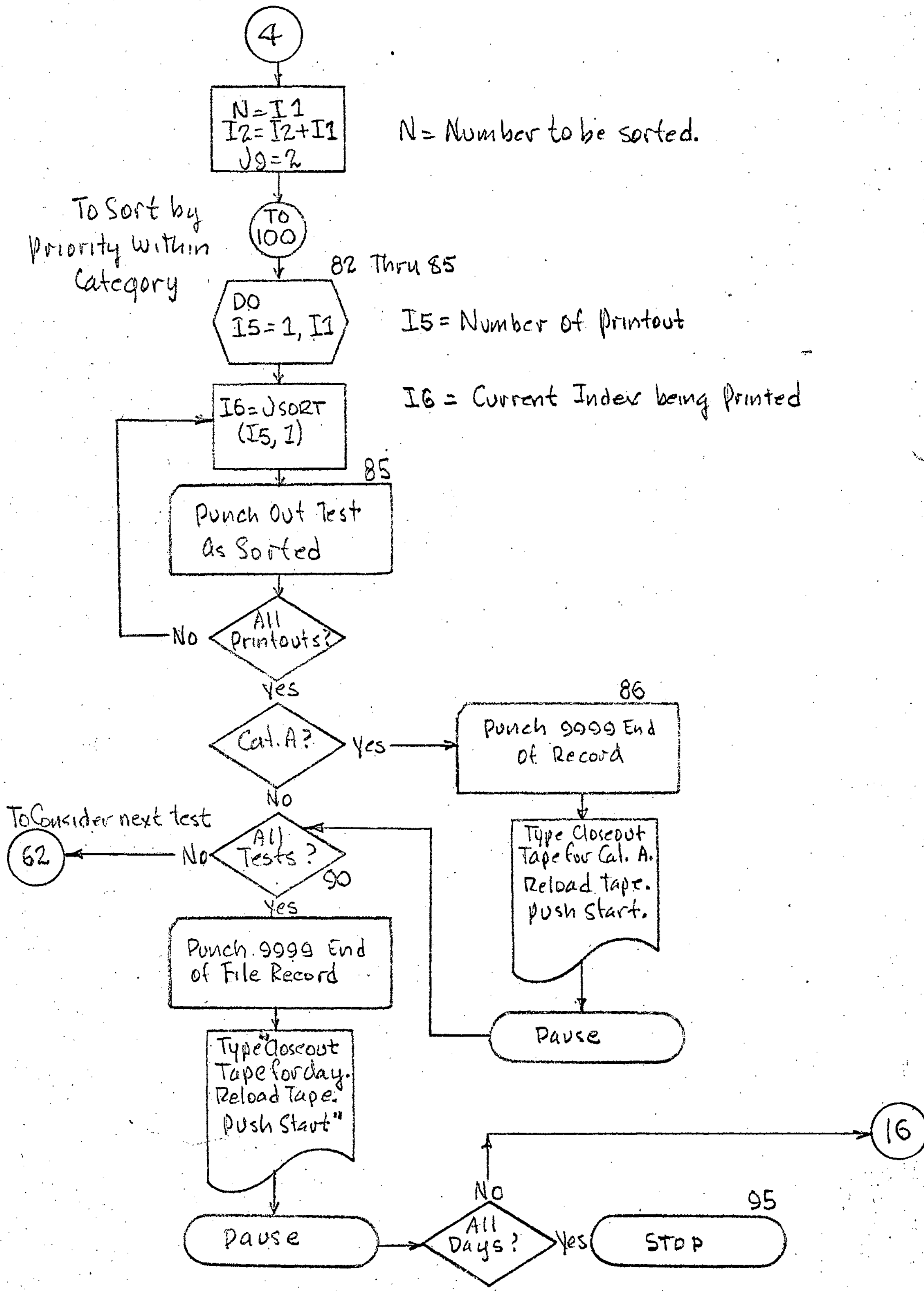


Figure 32 continued

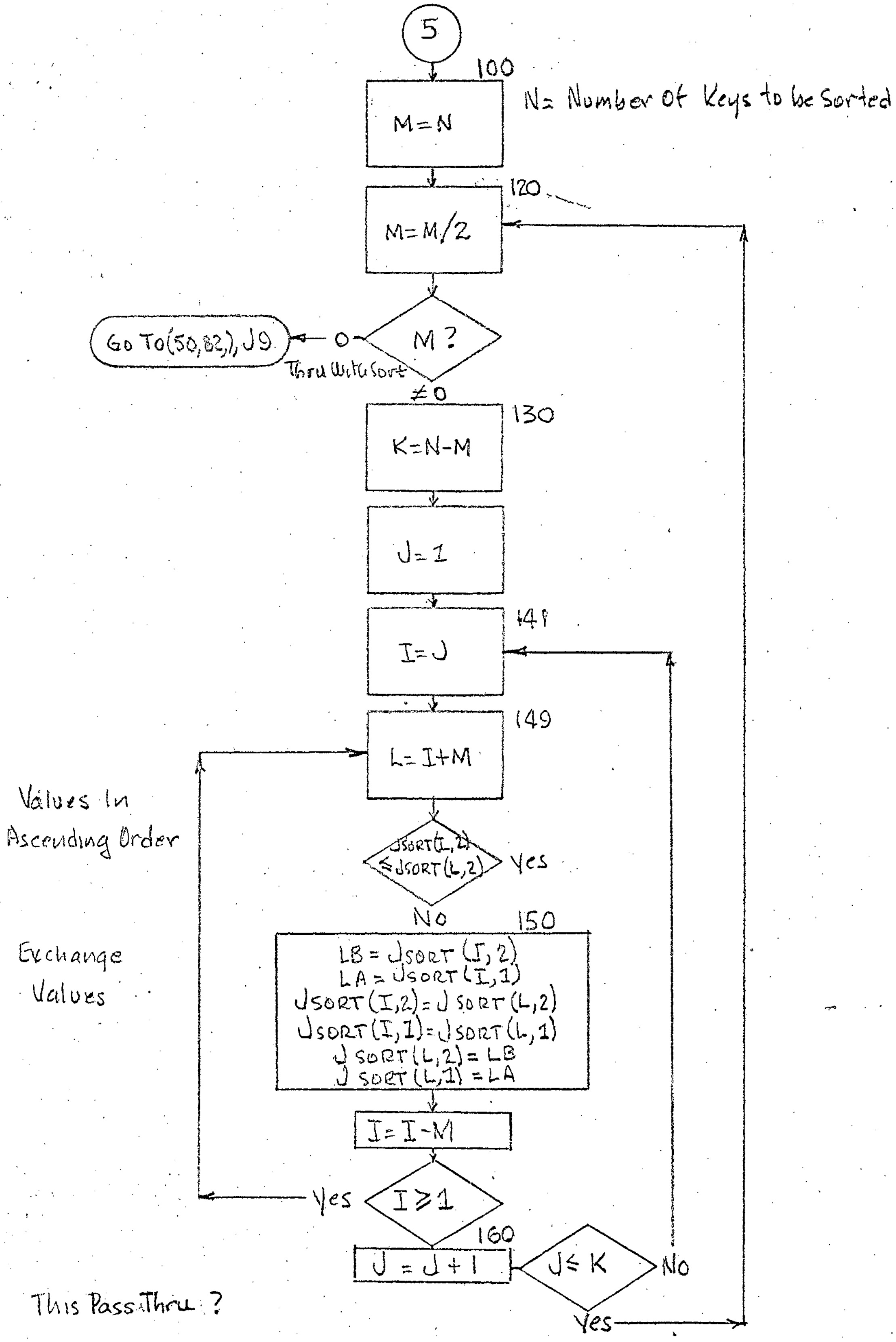


Figure 32 continued

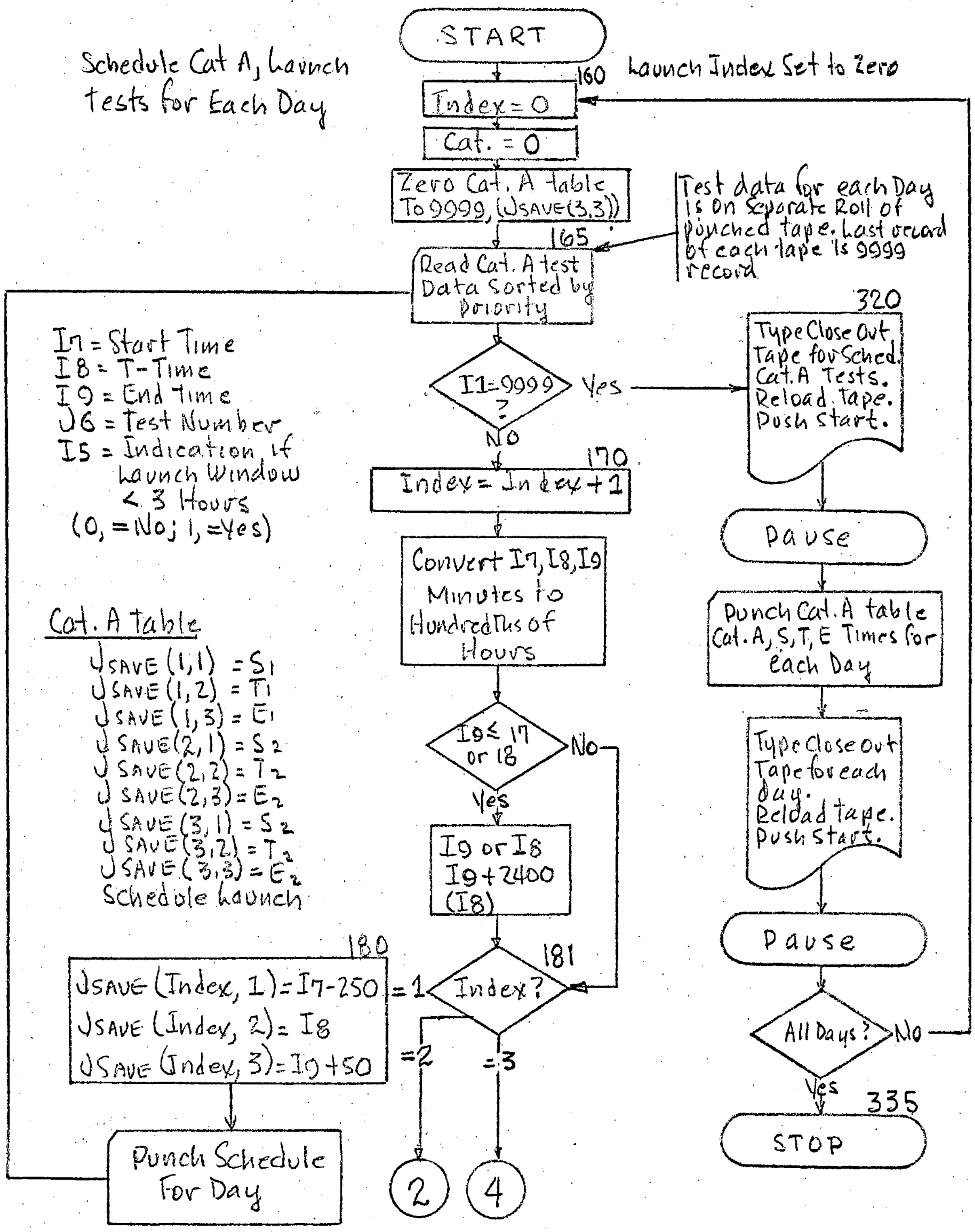


Figure 33. Machine Flow Diagram, Schedule Category A, Launch Tests, for Each Day (Pass II)

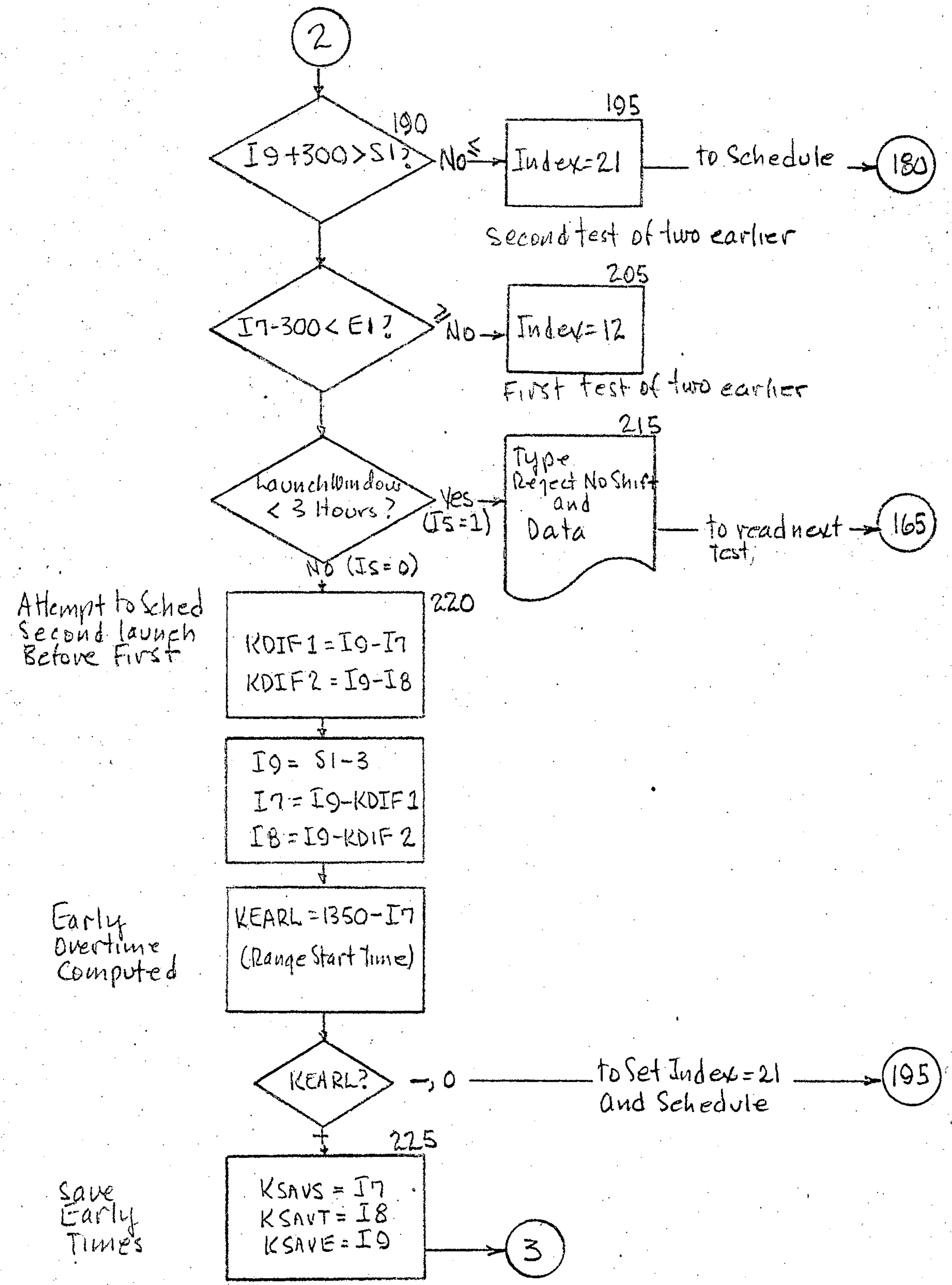


Figure 33 continued

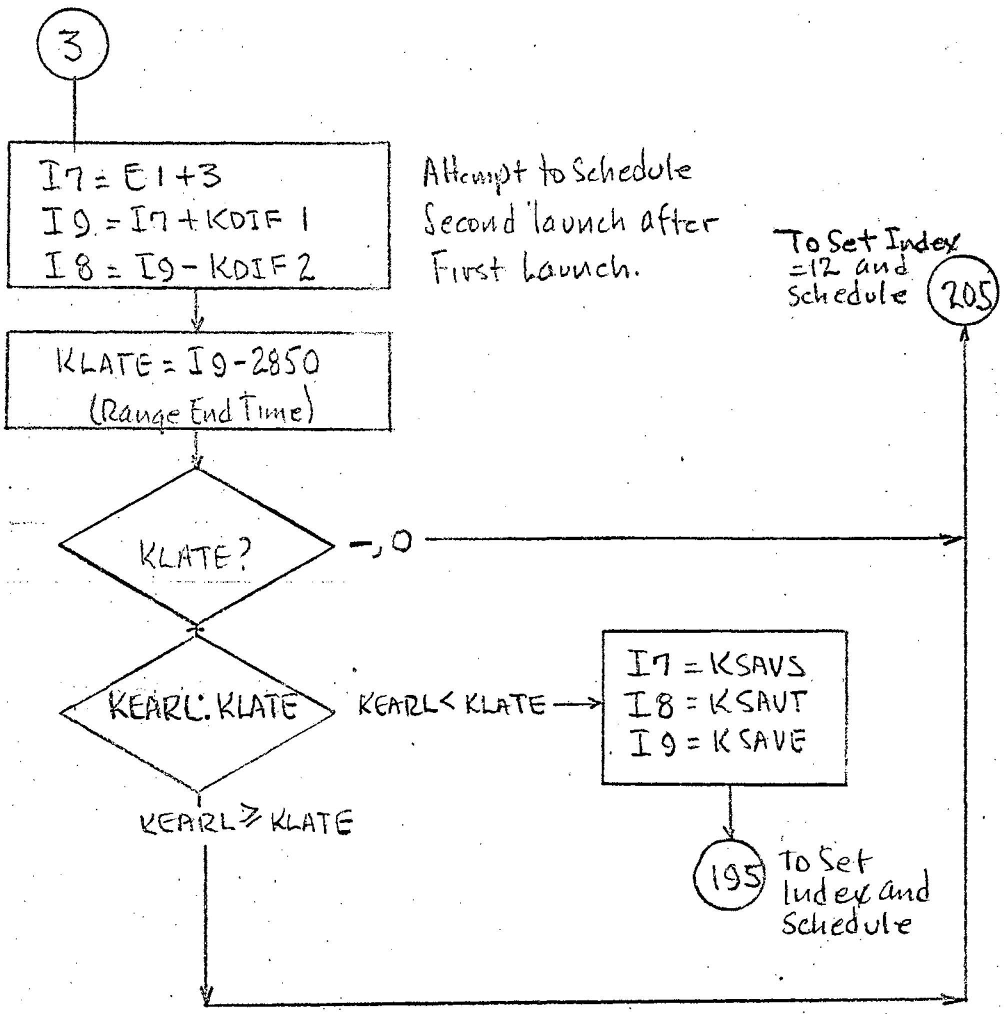


Figure 33 continued

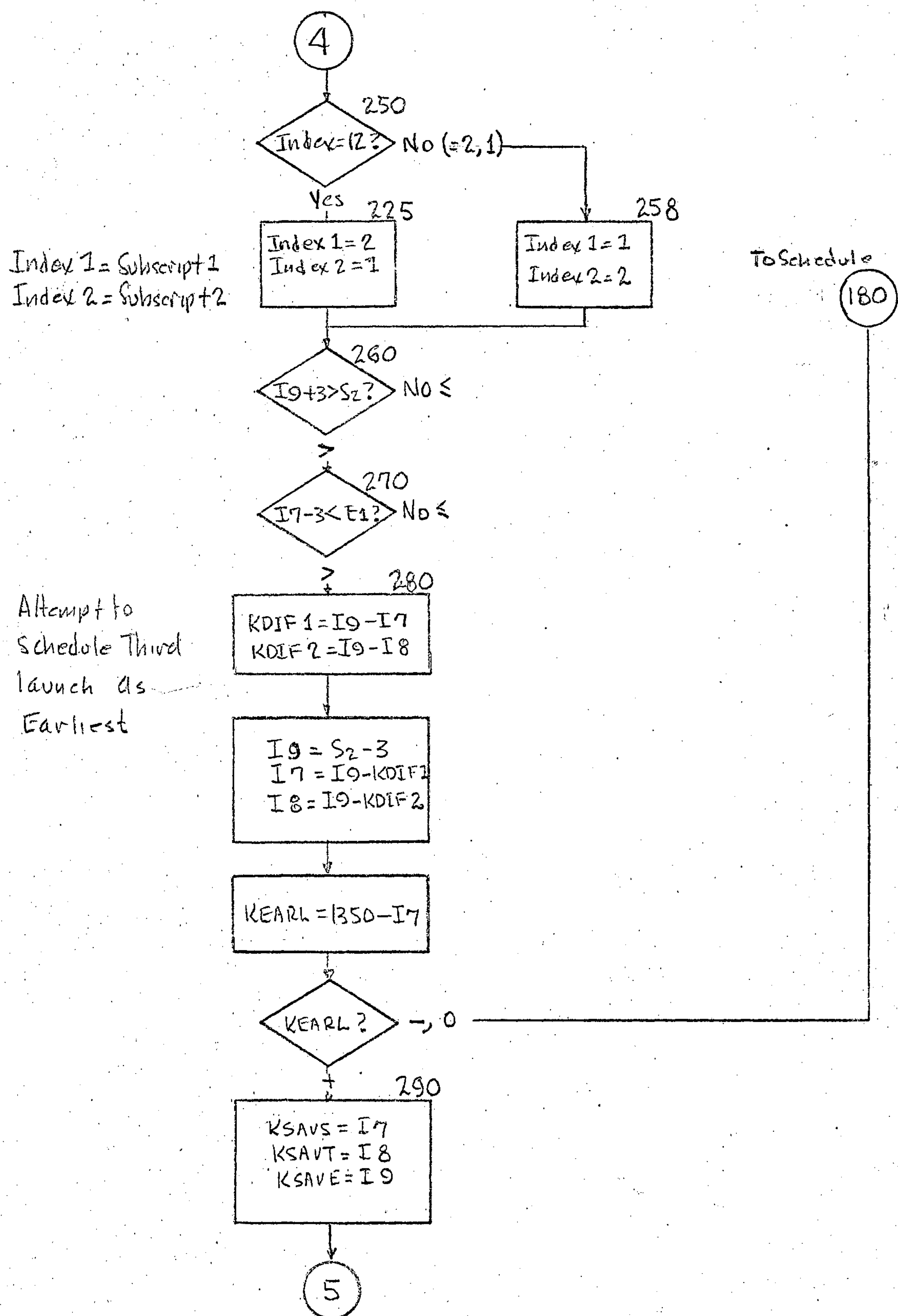


Figure 33 continued

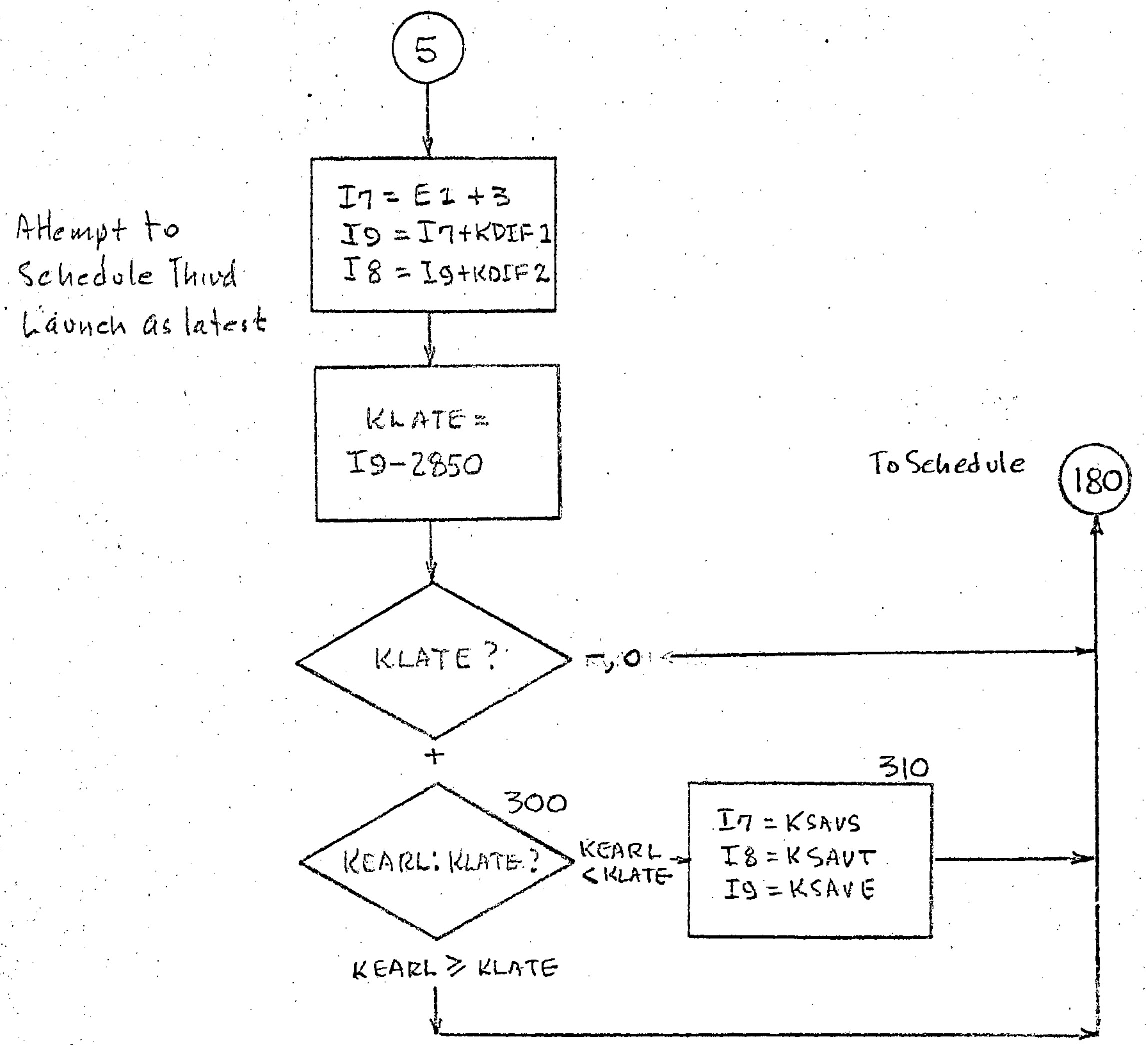


Figure 33 continued

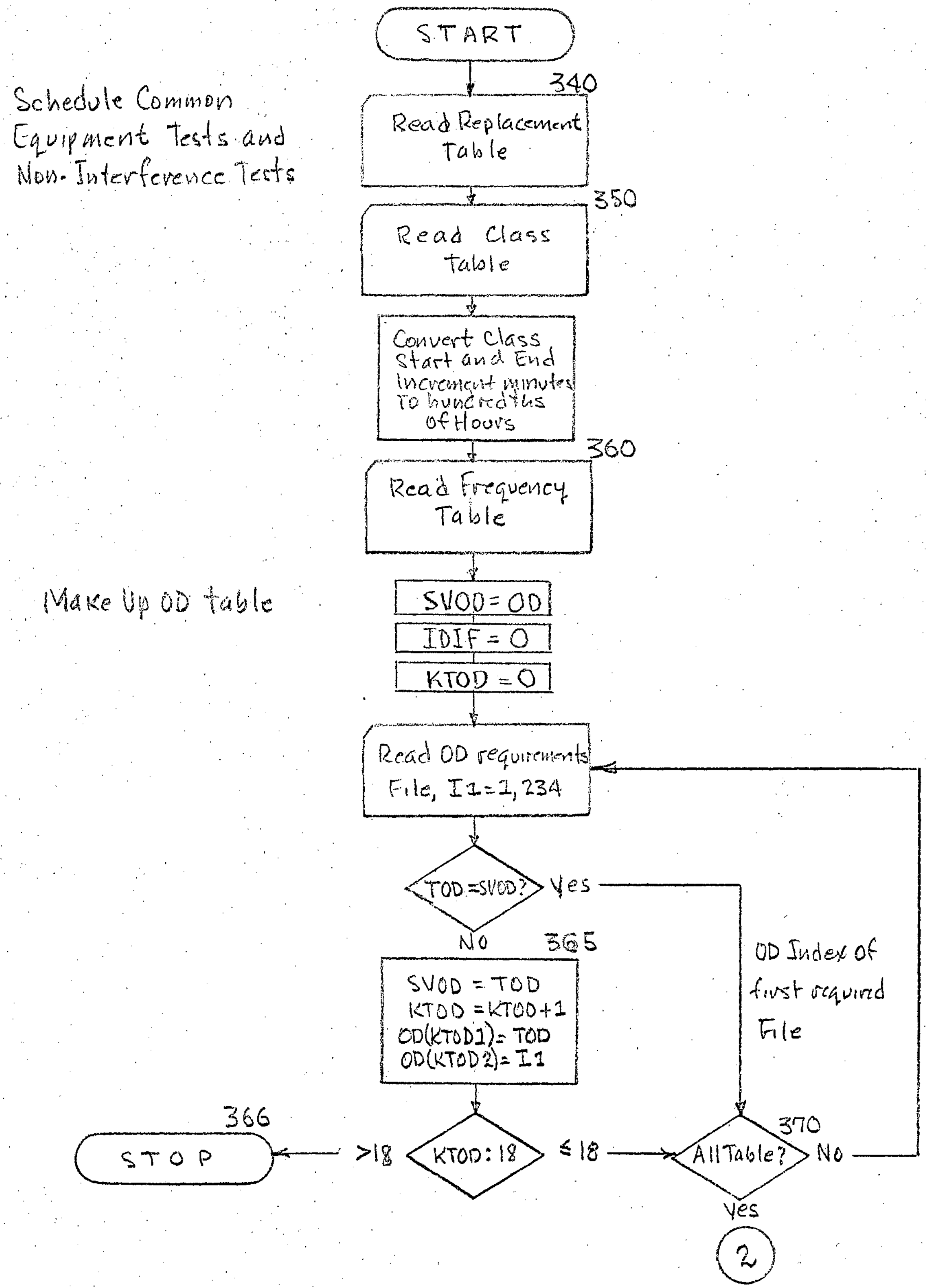


Figure 34. Machine Flow Diagram, Schedule Category B Thru H Support Tests by Day (Pass III)

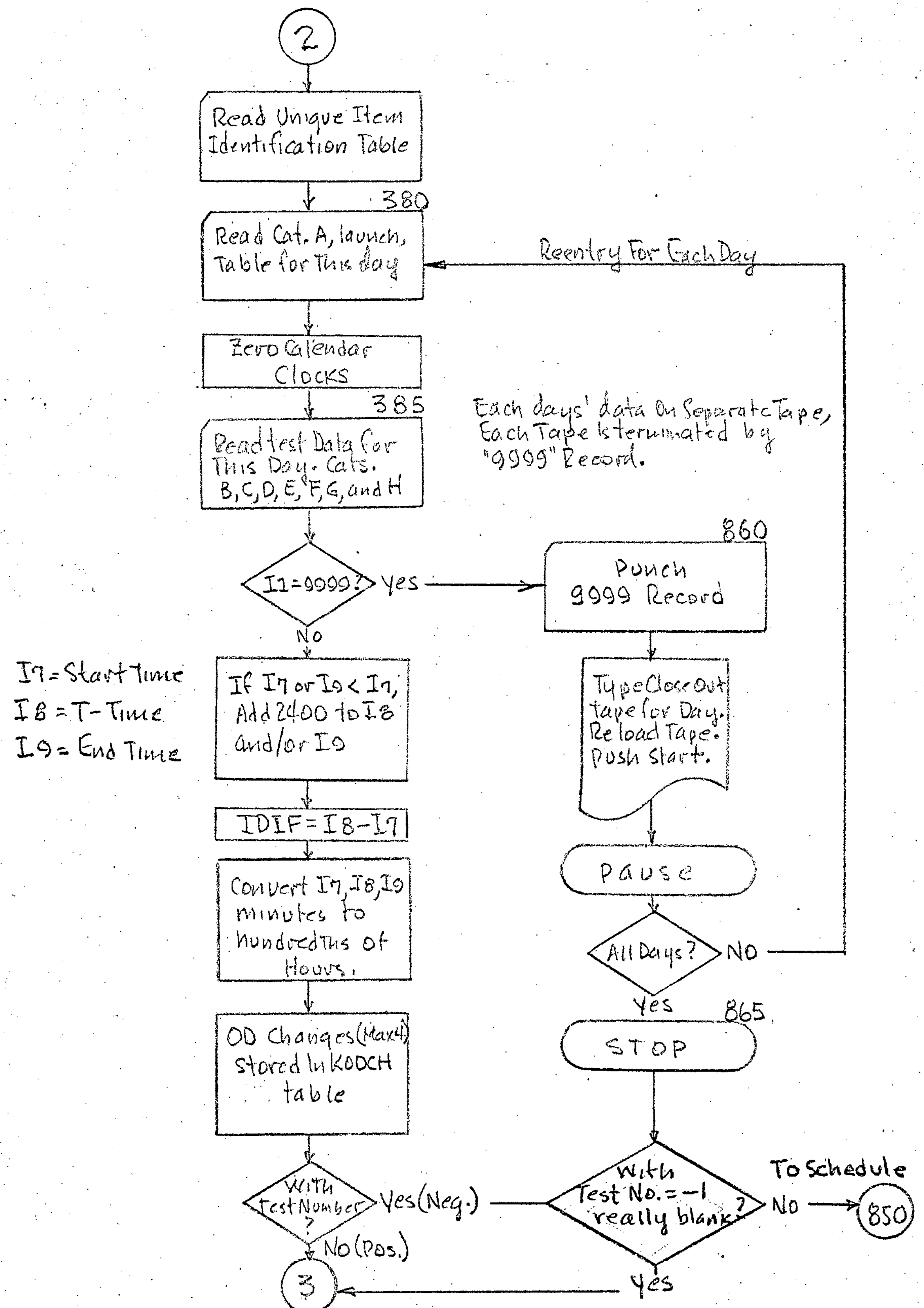


Figure 34 continued

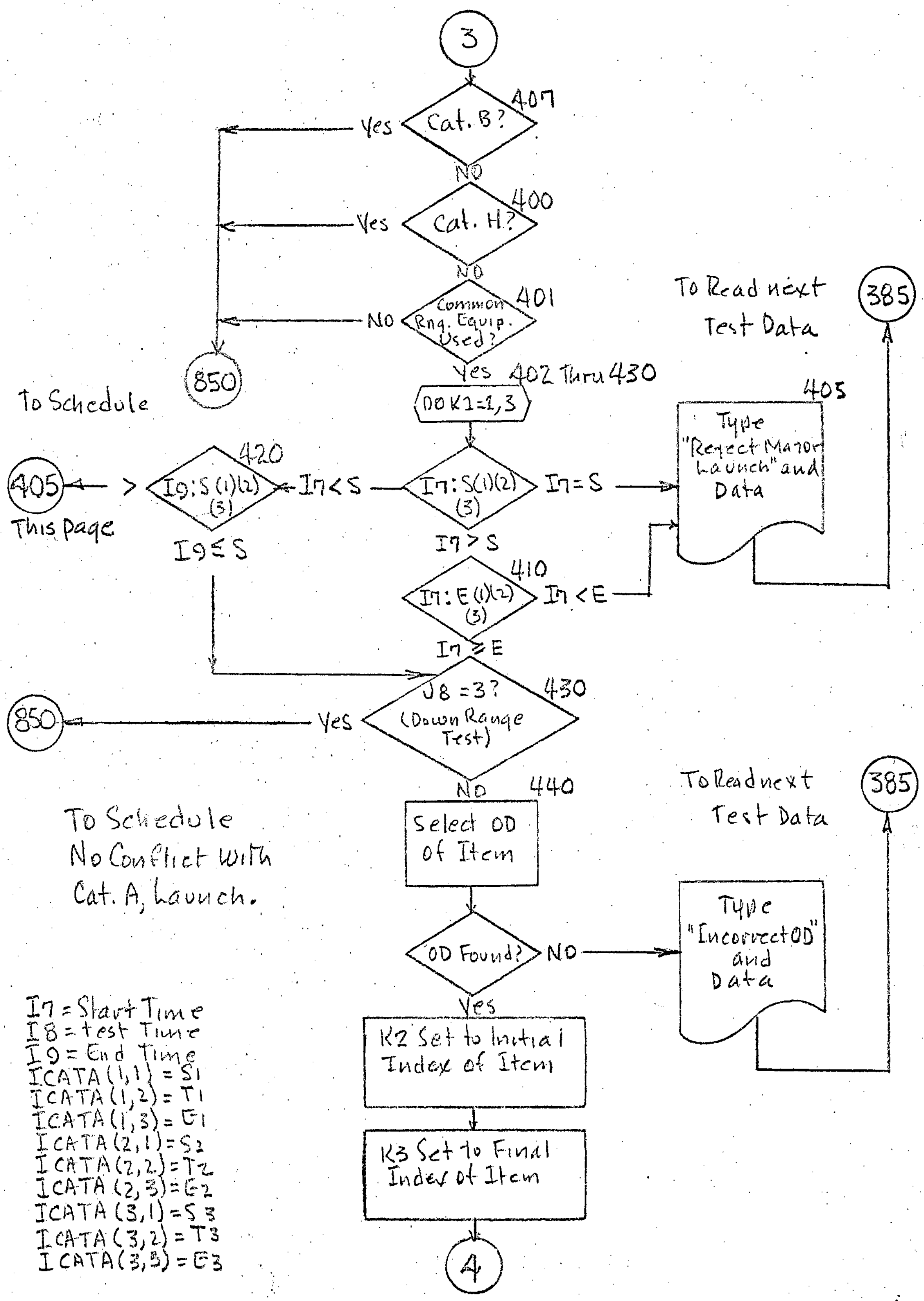


Figure 34 continued

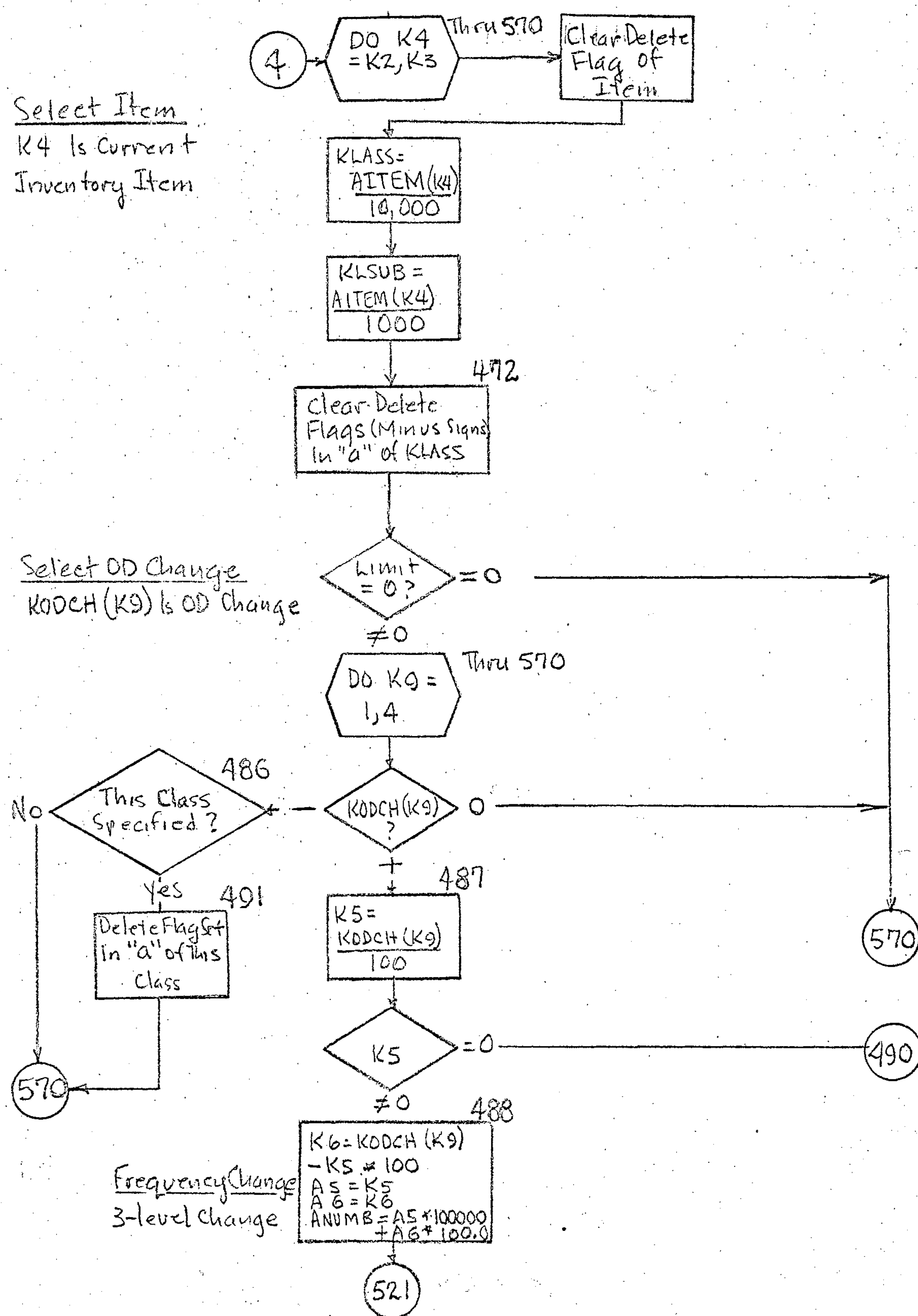


Figure 34 continued

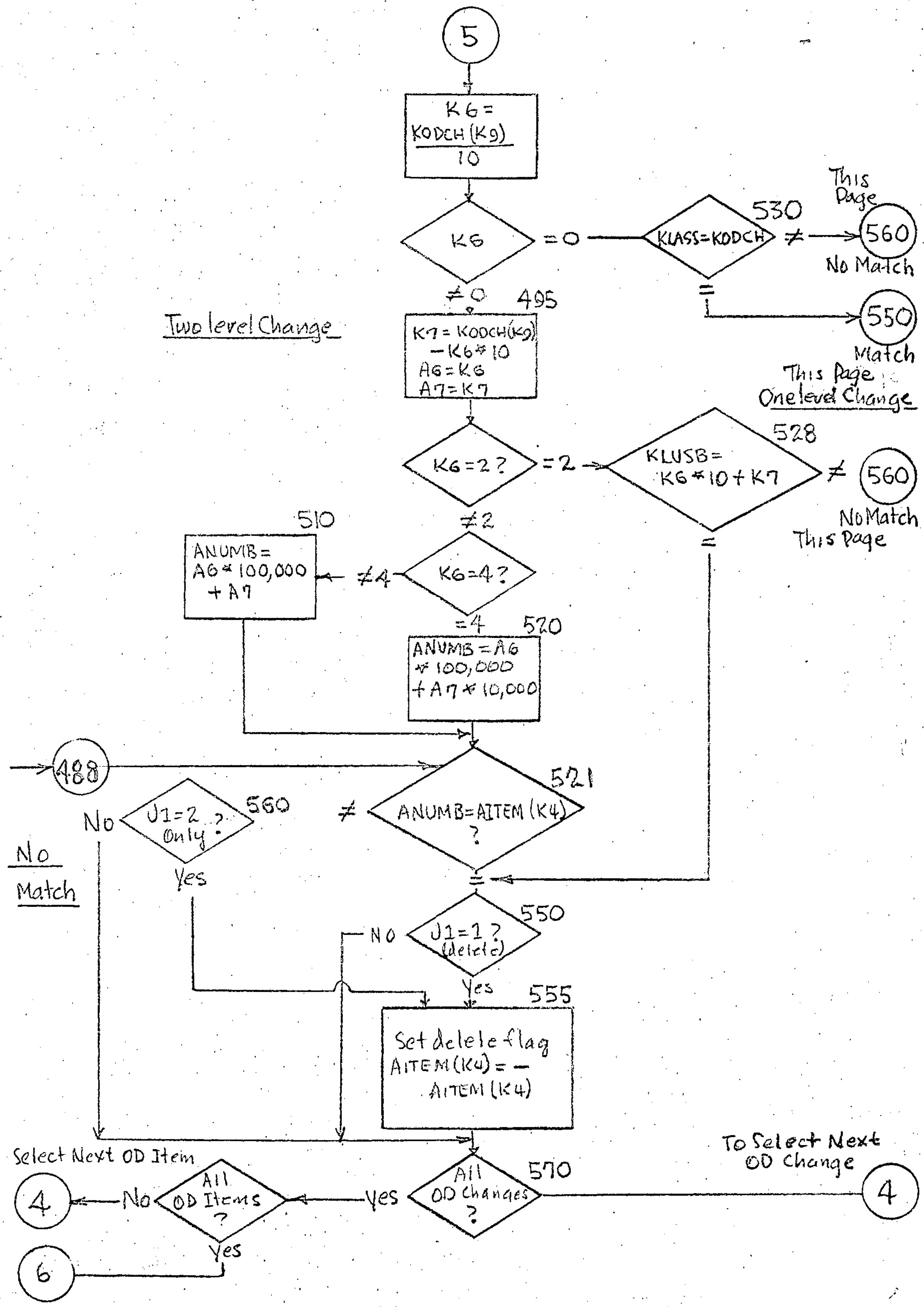


Figure 34 continued

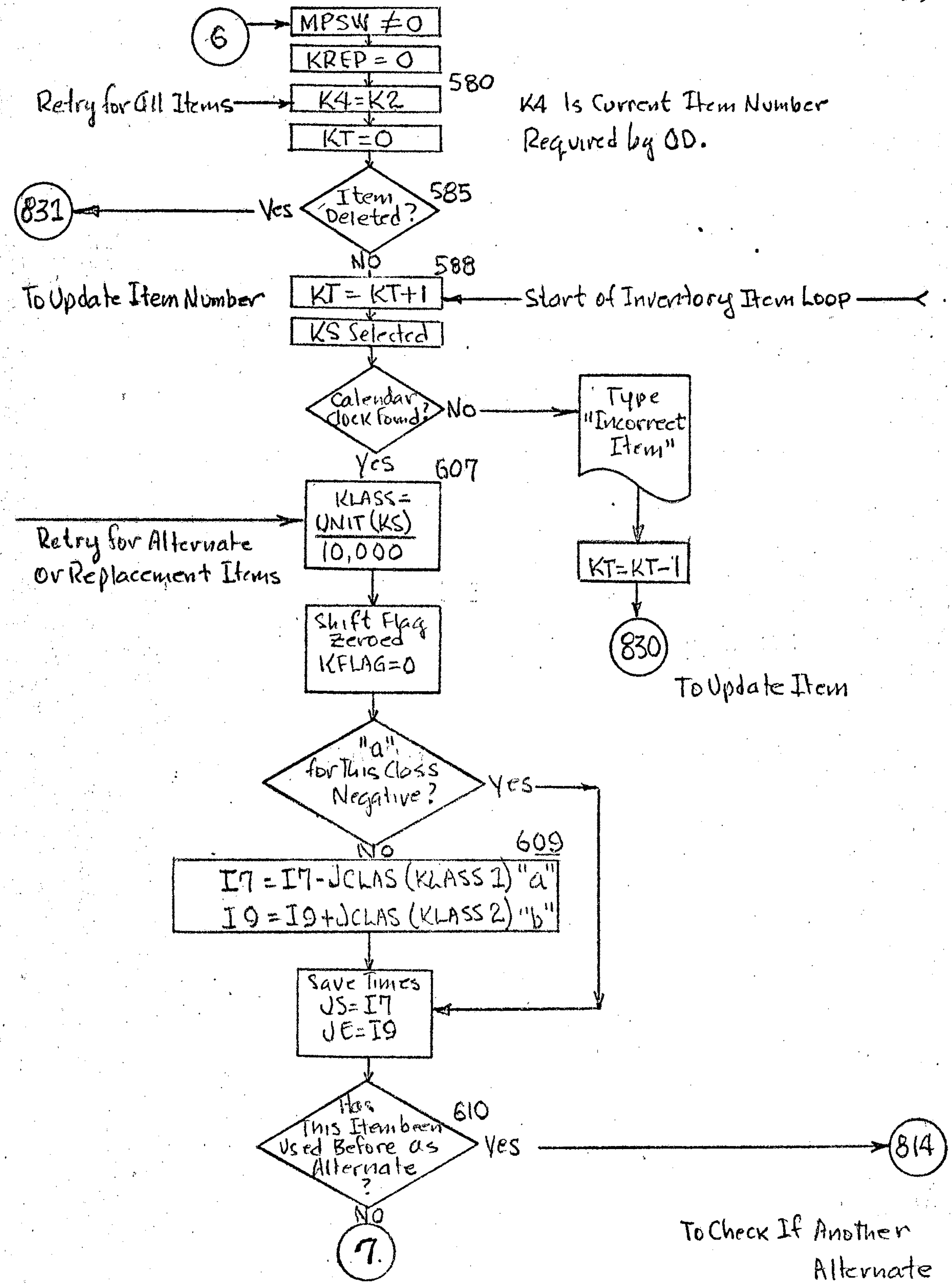


Figure 34 continued

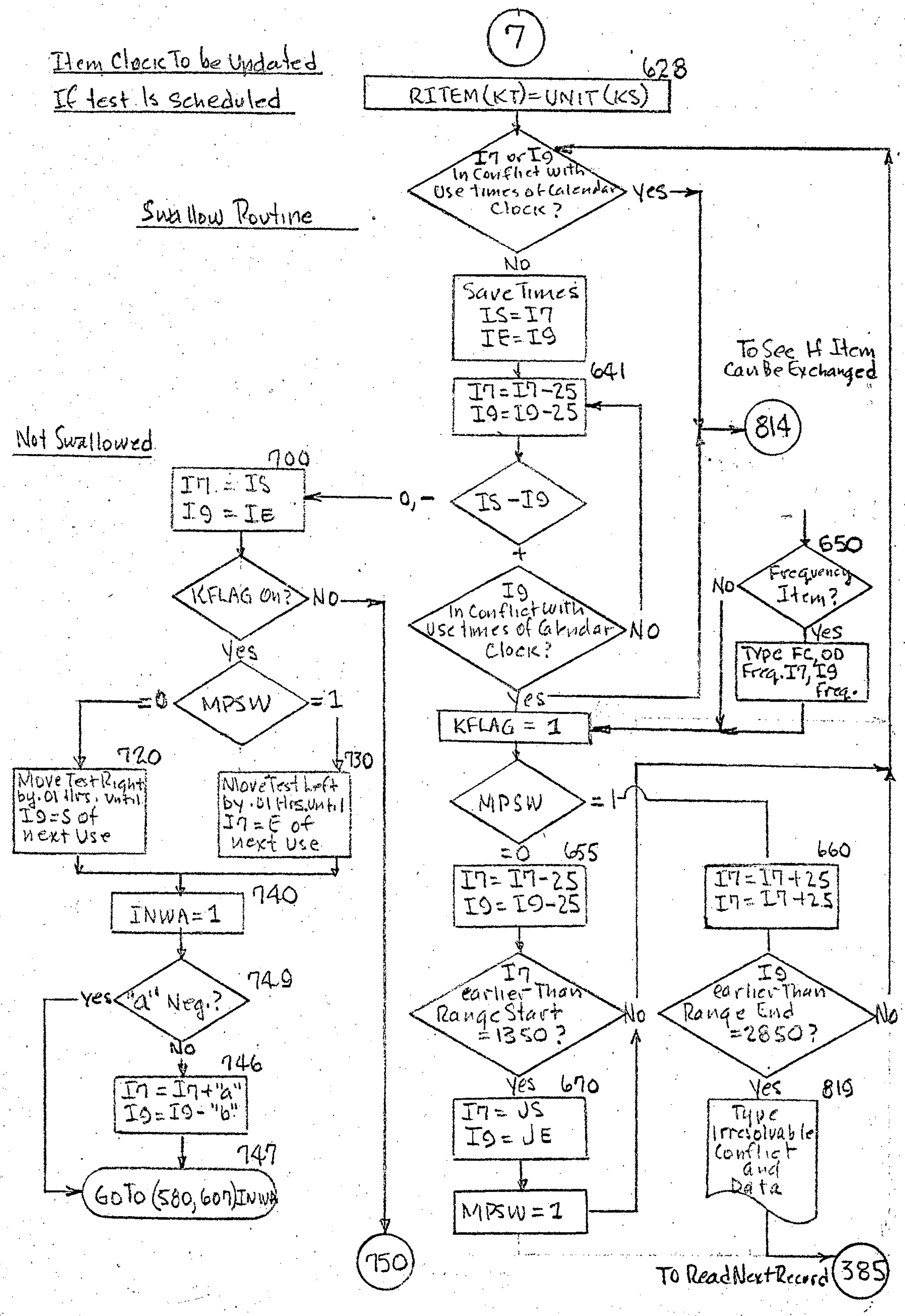


Figure 34 continued

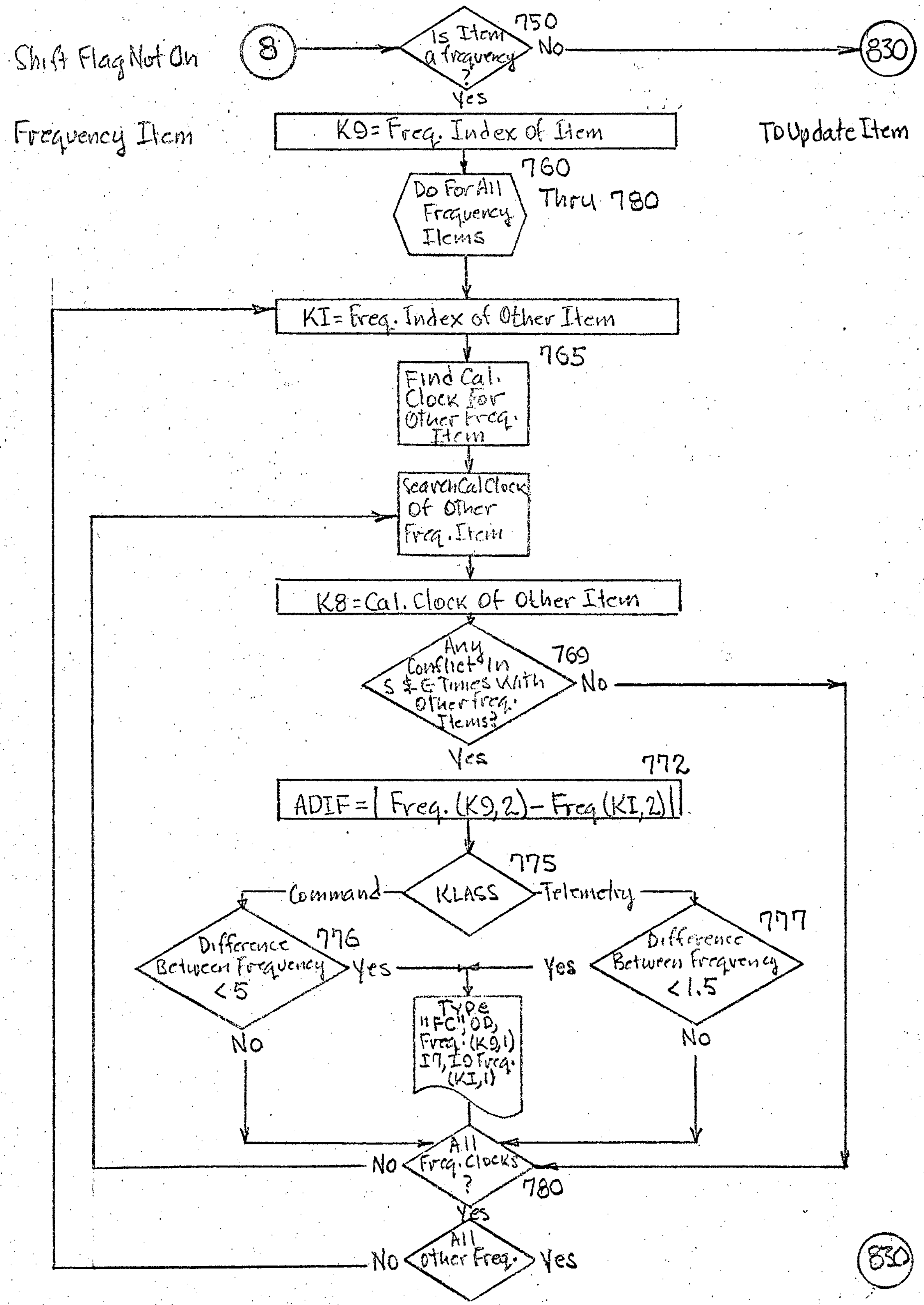


Figure 34 continued

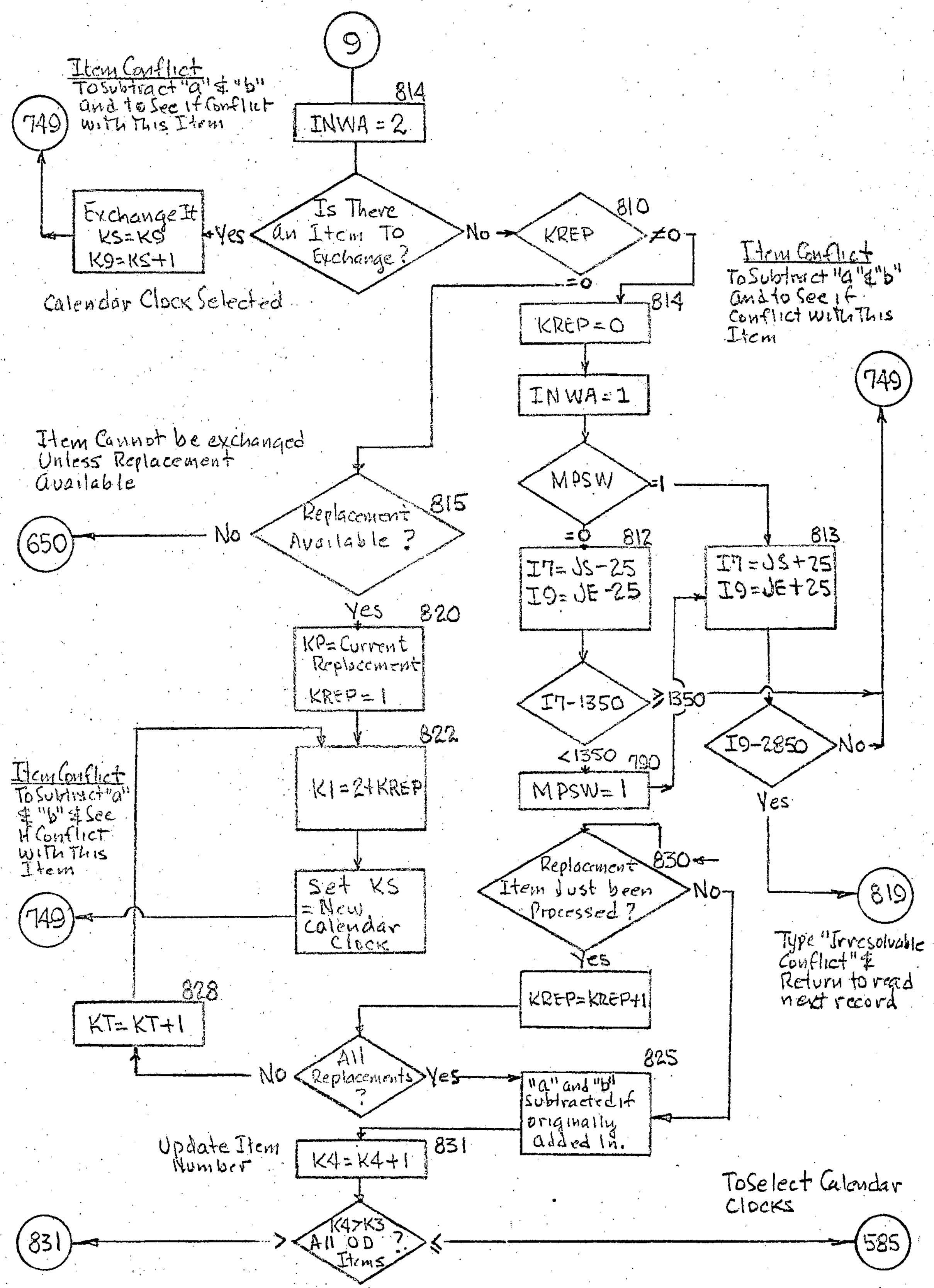


Figure 34 Continued

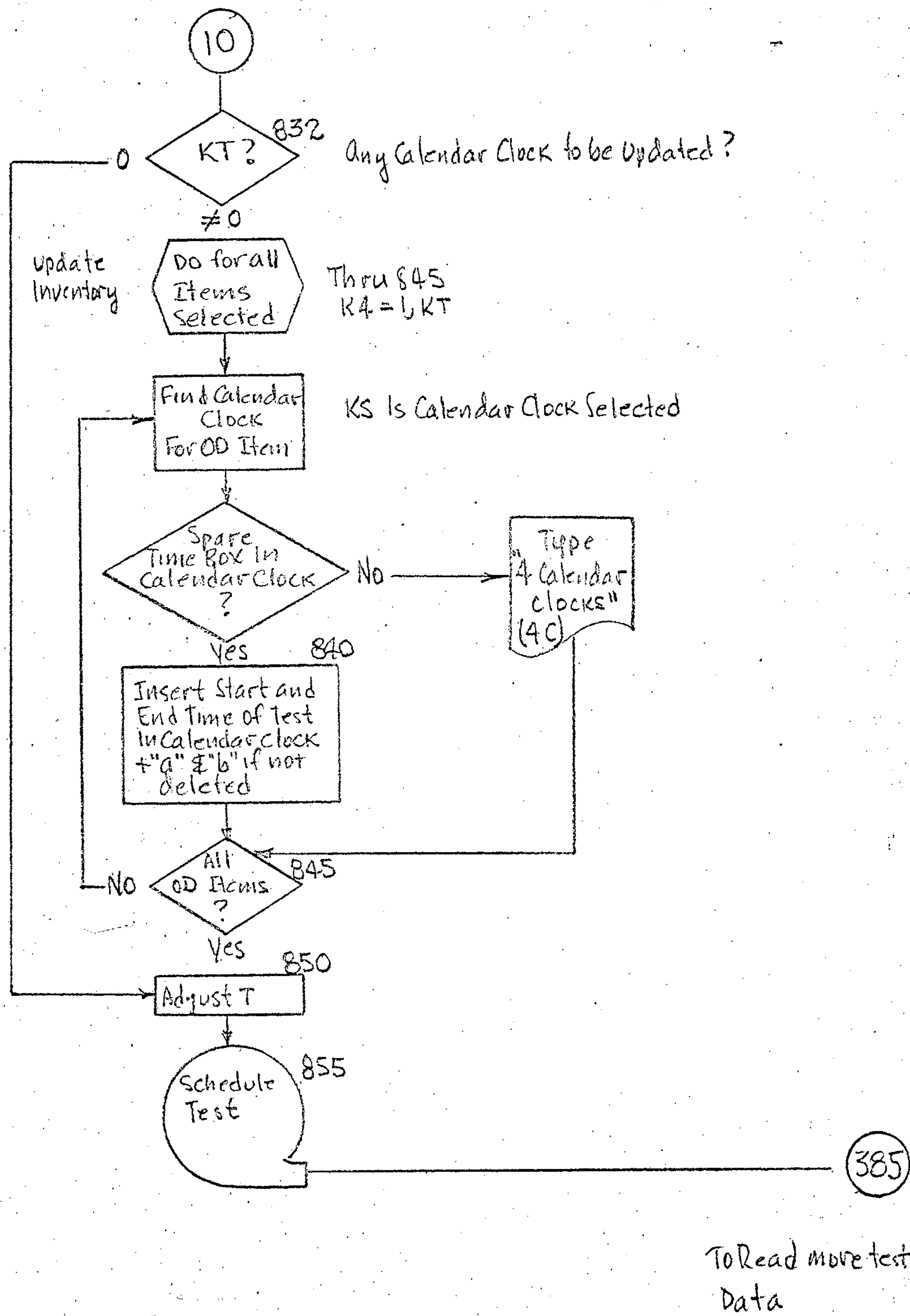


Figure 34 continued

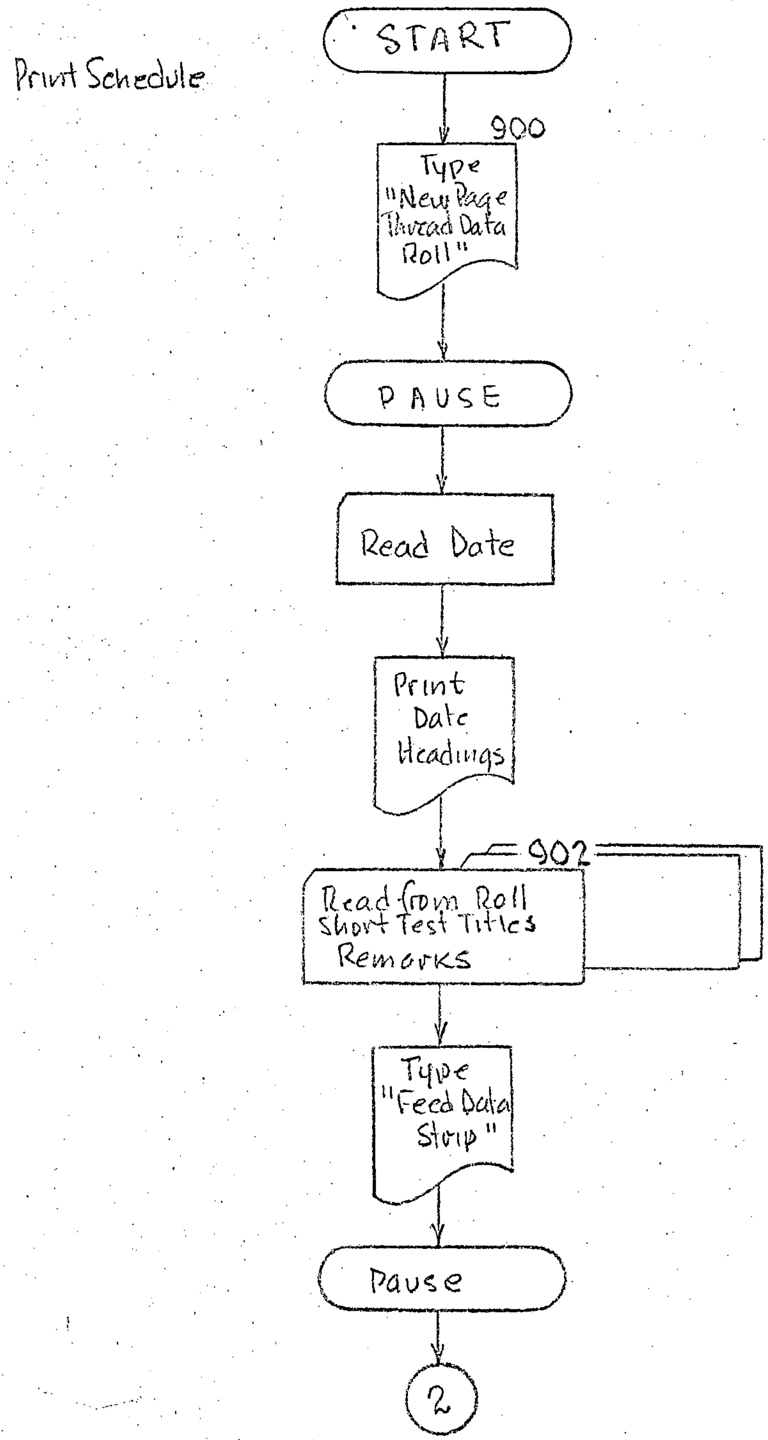


Figure 35. Machine Flow Diagram, Sort and Print Test Schedule by Day by Category with Pertinent Data, Short Test Titles, and Remarks (Pass IV)

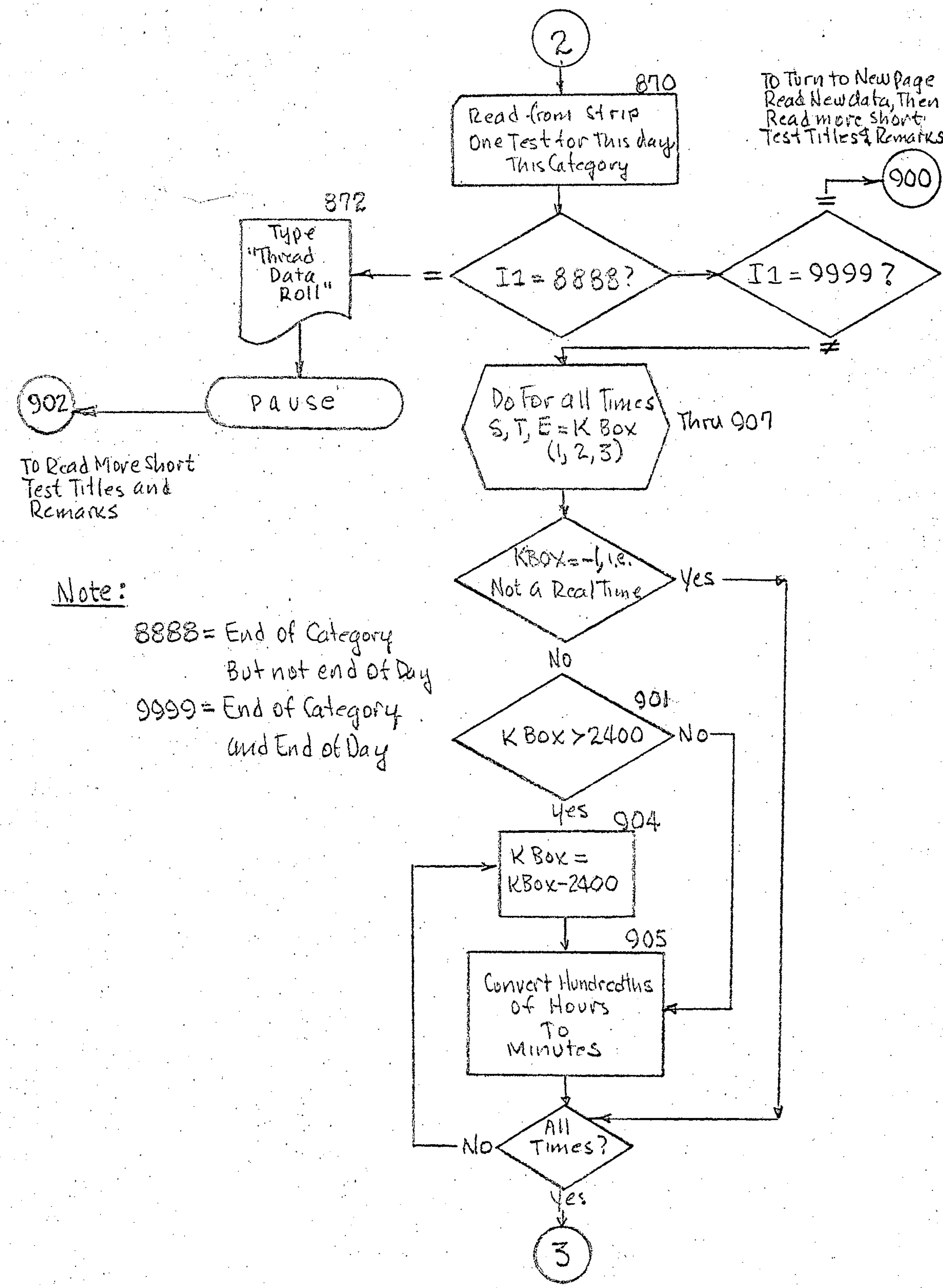


Figure 35 continued

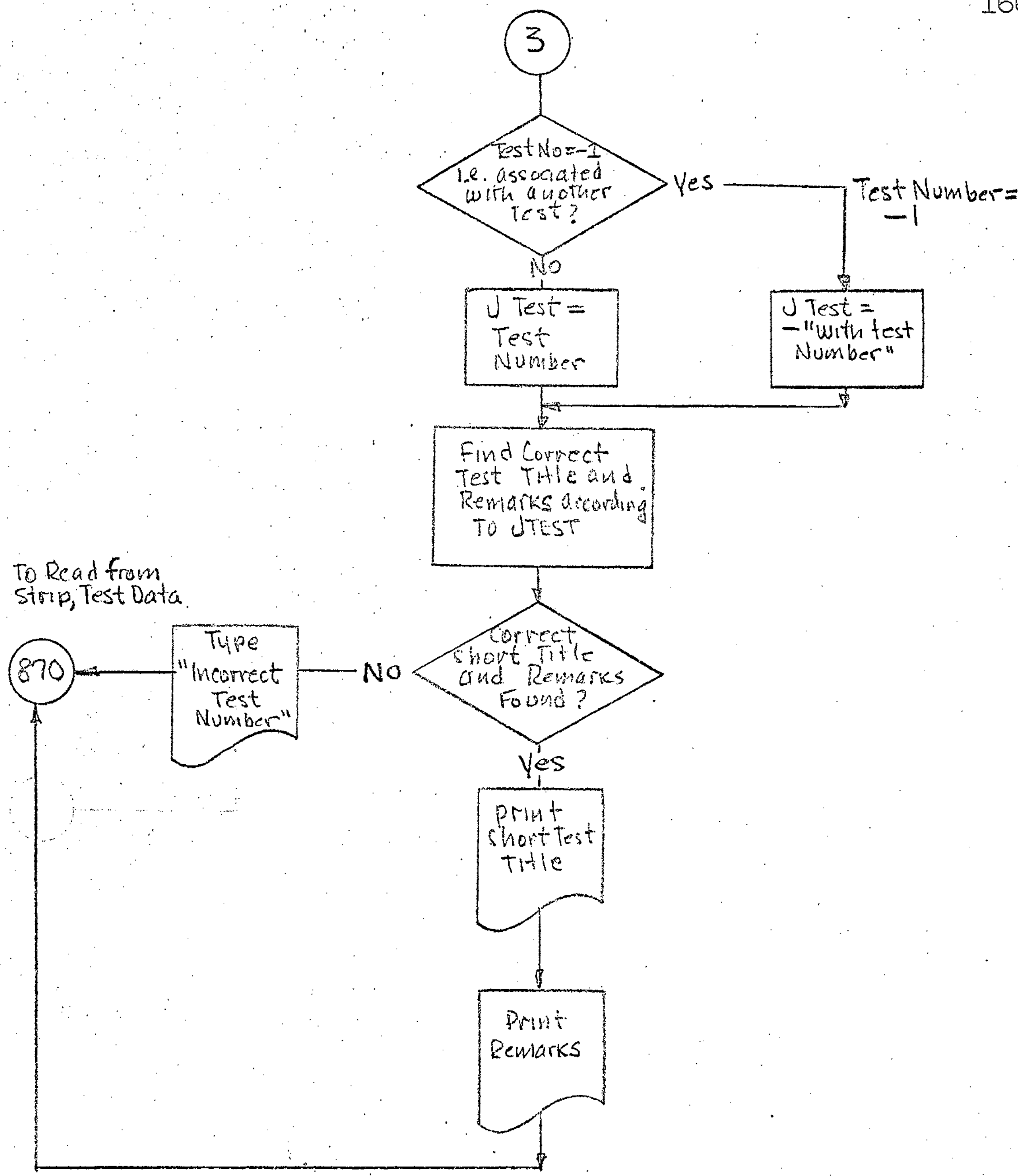
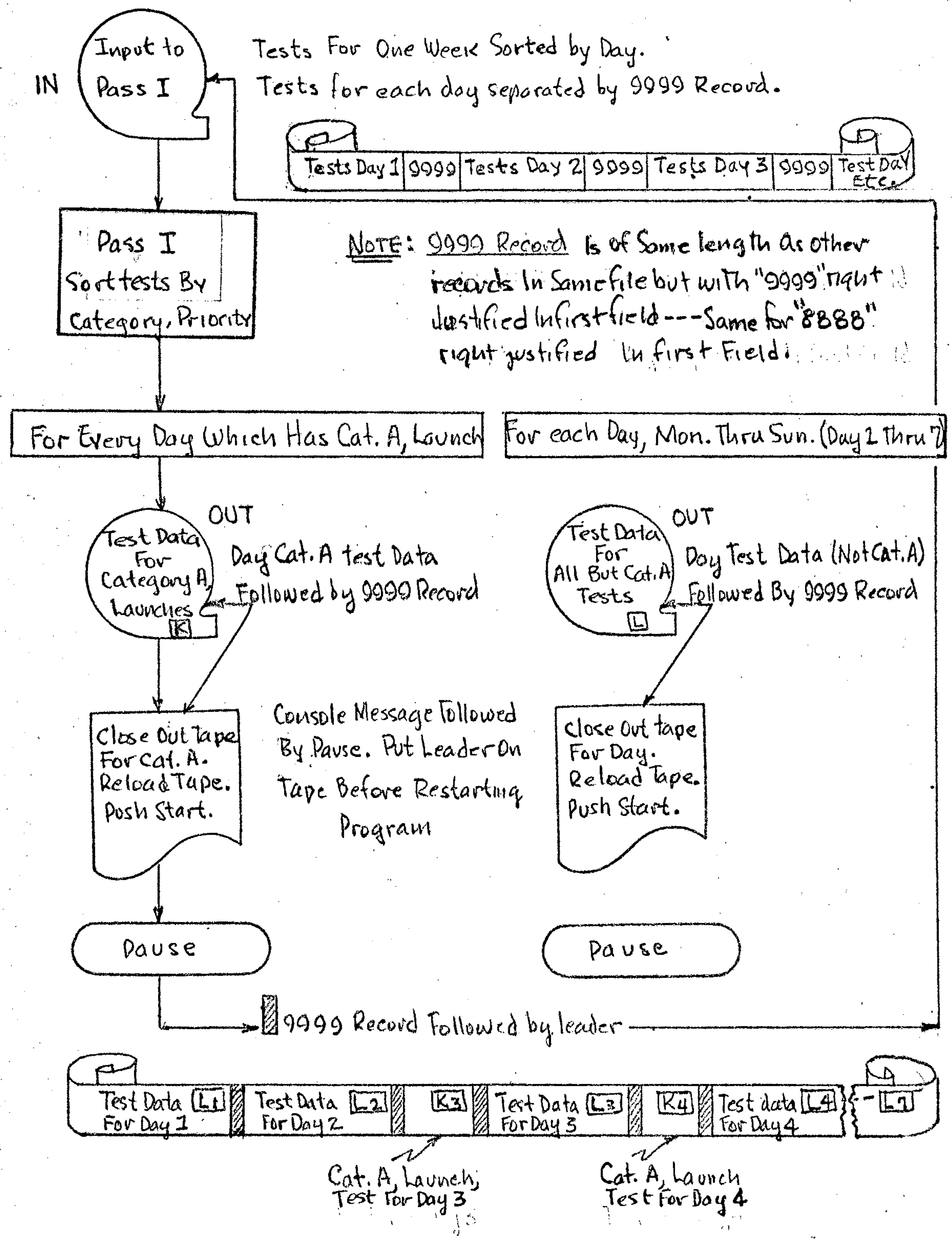


Figure 35 continued

INSTRUCTION 1. RUN PASS I

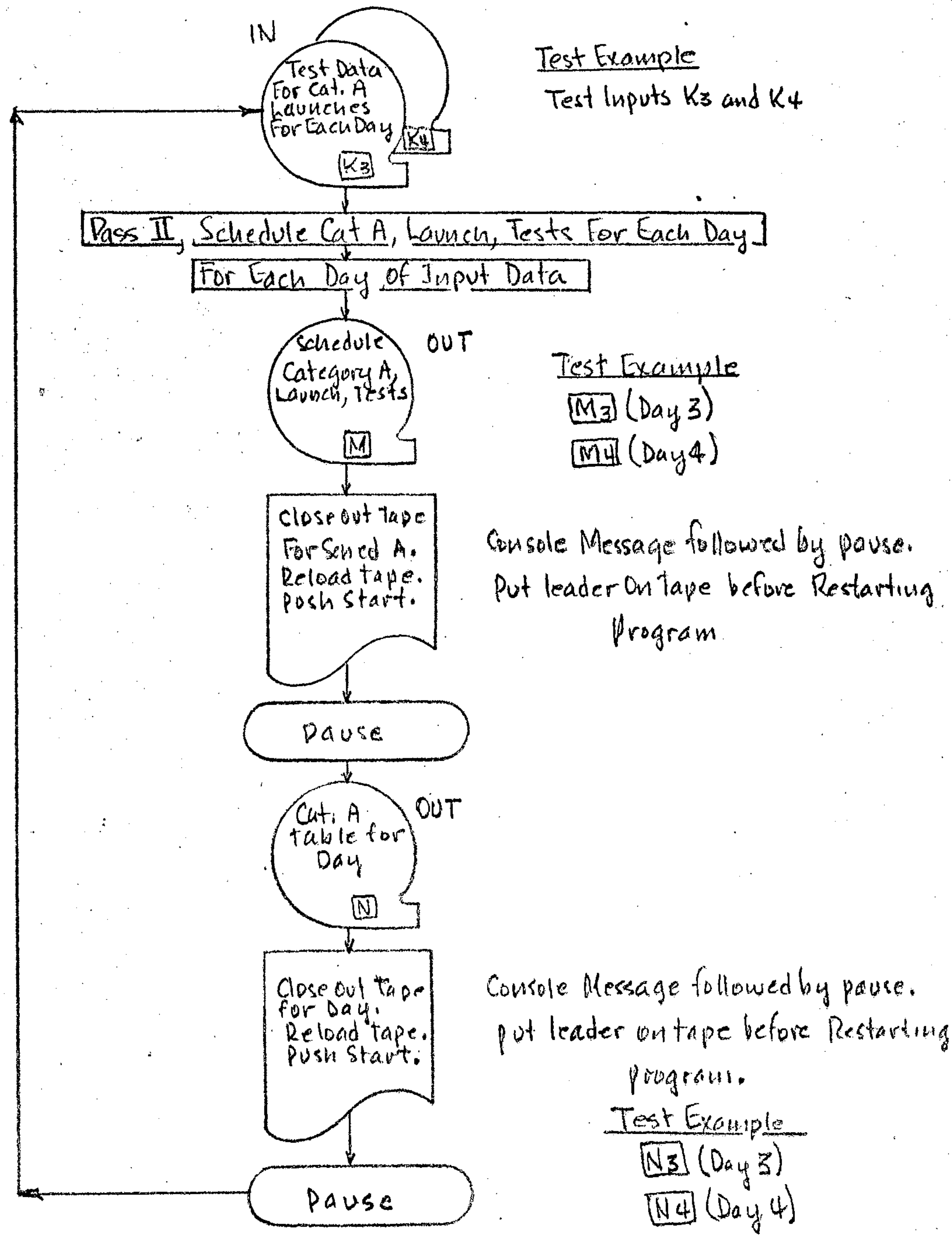


STOP Will Print at end of Program.

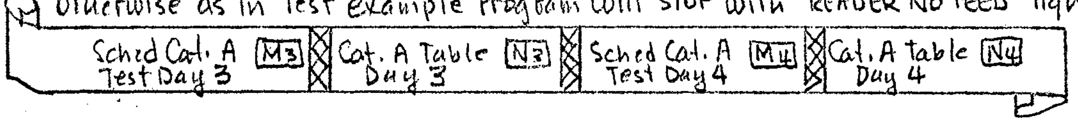
INSTRUCTION 2. CUT PASS 1 OUTPUT INTO STRIPS TERMINATED BY 9999 RECORD

Figure 36. Floor Procedure for Running Machine Scheduling Program

INSTRUCTION 3. RUN PASS II



If Input Consists of 7 days of Cat. A, Launch, Tests, STOP will Print at end, Otherwise as In Test example Program will STOP with 'READER NO FEED' light On



INSTRUCTION 4. CUT OUTPUT INTO STRIPS

Figure 36 continued

INSTRUCTION 5. MAKE CAT. A TABLE FOR DAYS WITH NO CAT A, LAUNCHES; THREE RECORDS OF THREE FIELDS EACH, 6 CHARACTERS EACH FIELD CONTAINING 9999 RIGHT JUSTIFIED D_1, D_2, D_5, D_6, D_7

INSTRUCTION 6. RUN PASS III

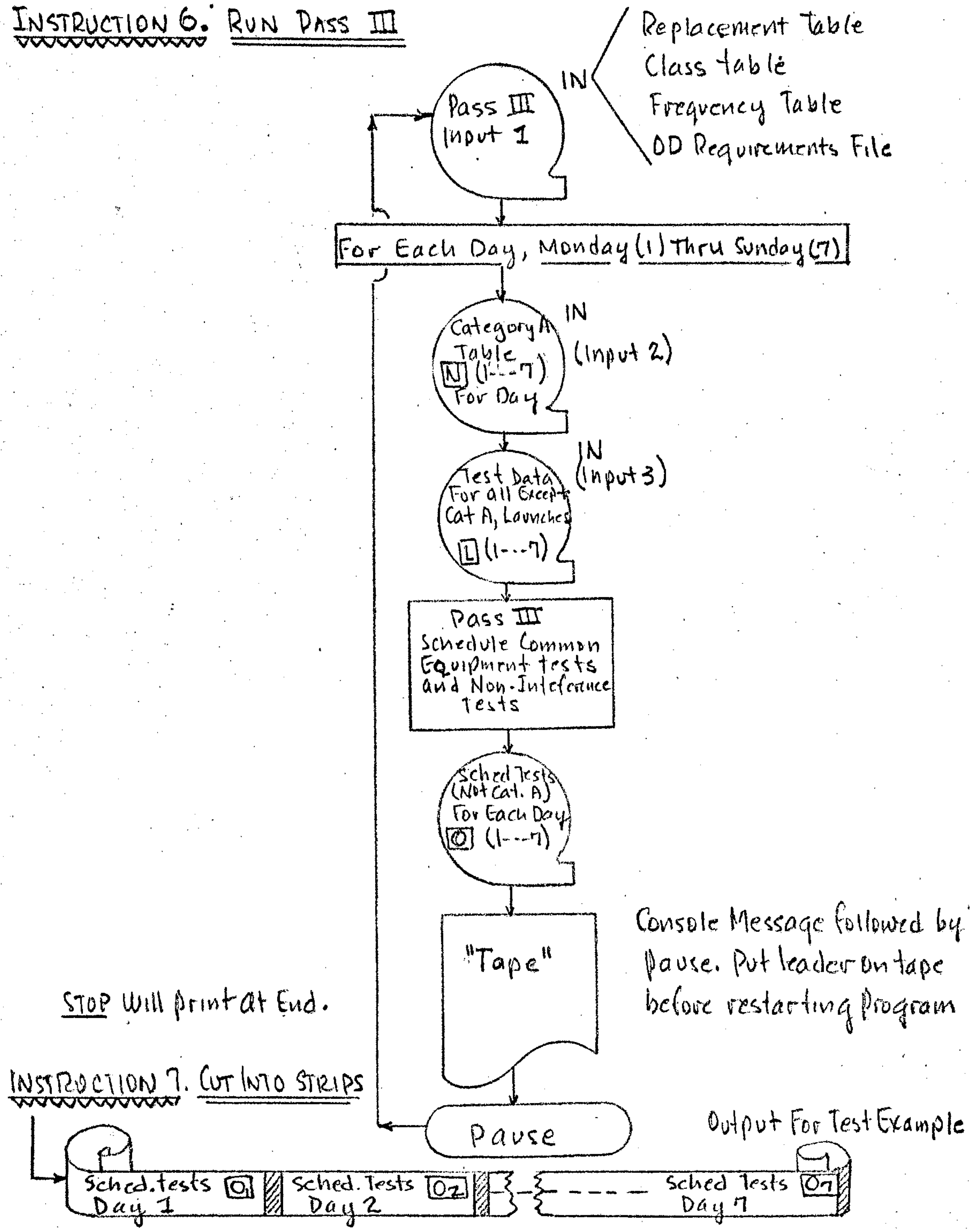
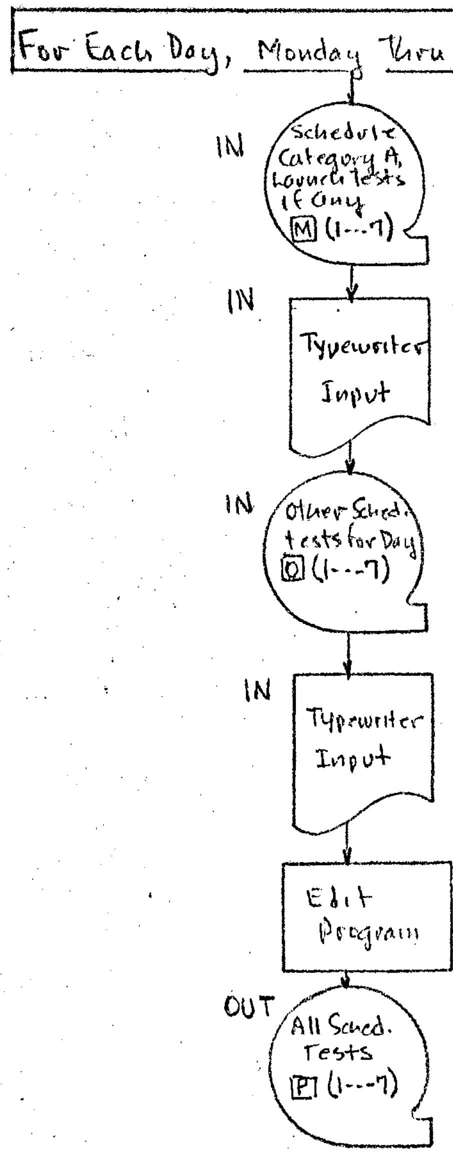


Figure 36 continued

INSTRUCTION 8. EDIT SCHEDULED TEST OUTPUT OF PASS II AND PASS III

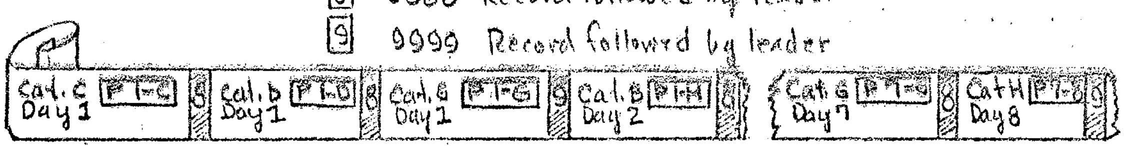


Each Set of tests Of one Category followed by 8888 Record (Except last Category For Day which is followed by 9999 Record) and a Leader.

Output For Test Example

8 8888 Record followed by leader

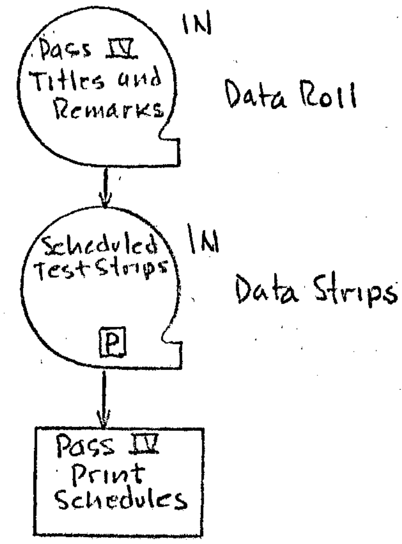
9 9999 Record followed by leader



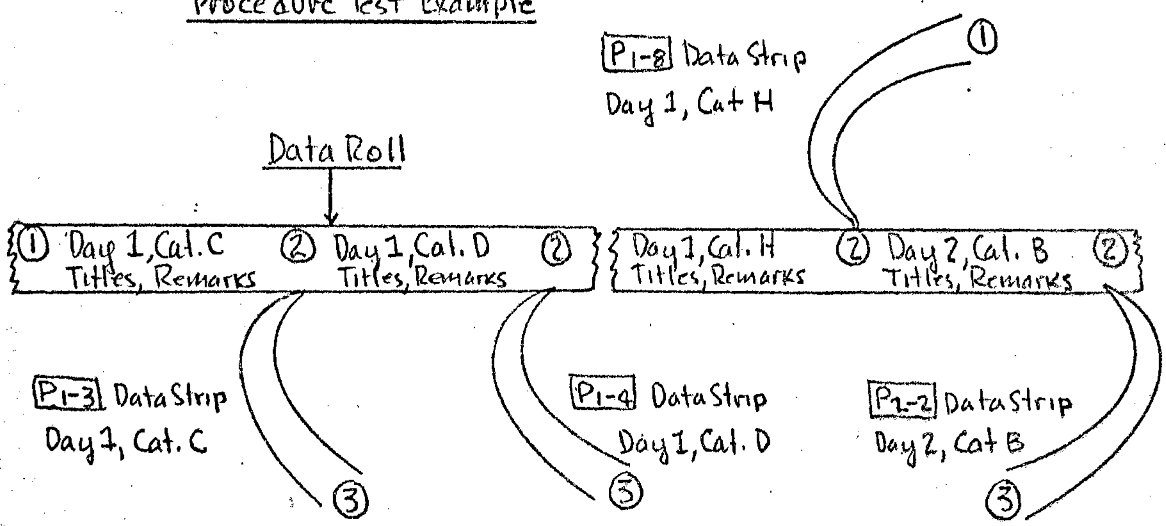
INSTRUCTION 9. CUT INTO STRIPS

Figure 36 continued

INSTRUCTION 10. RUN PASS IV



Procedure Test Example



Typewriter Messages At numbered Points

① "New Page, Thread Data Roll

② "Feed Data Strip"

③ "Thread Data Roll"

Program Will End With 'Reader No Feed' light On →

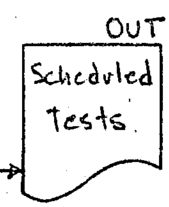


Figure 36 continued

VITA

Frederick Frakes Fennema

Candidate for the Degree of

Doctor of Philosophy

Thesis: SCHEDULING AGAINST A PROBABALISTIC DEMAND IN A HEURISTIC ENVIRONMENT

Major Field: Engineering

Biographical:

Personal Data: Born near Lawton, Oklahoma, October 5, 1918, the son of Gerrit and Blanche Melton Fennema.

Education: Attended Clinton, Oklahoma schools graduating from High School in 1936; received the Bachelor of Science degree from the Oklahoma State University, with majors in Aeronautical and Mechanical Engineering, in May 1941; received the Master of Science degree from the Oklahoma State University, with a major in Industrial Engineering, in August 1962; completed requirements for the Doctor of Philosophy degree in May 1964.

Professional experience: Employed by Lockheed Aircraft Corporation, Burbank, California from June 1941 to March 1943. Accepted a Civil Service appointment as an Operations Analyst serving the 20th Air Force in the Mariannas Island area during World War II until September 1945. Employed by American Airlines, LaGuardia Field, New York as supervisor, Operational Engineering, until October 1947. Again accepted a Civil Service appointment as an Operations Research Analyst with the United States Air Force in October 1947 serving to the present the organizations at the locations listed below. Alaskan Air Command, Anchorage, Alaska, 2 years; Strategic Air Command, Omaha, Nebraska, 5 years; Headquarters 12th Air Force (US/NATO), Ramstein, Germany, 2 years; Air Force Missile Test Center, Patrick Air Force Base, Florida, 6 1/2 years.