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An evaluation of calendar based preventive maintenance system versus usage based preventive maintenance system.

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AN EVALUATION OF CALENDAR BASED PREVENTIVE MAINTENANCE SYSTEM VERSUS USAGE BASED PREVENTIVE MAINTENANCE SYSTEM

by

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CERTIFICATE OF APPROVAL

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ABSTRACT

Preventive Maintenance Systems as a rule do not lend themselves to easy evaluation as to effectiveness. No one PM (Preventive Maintenance) scheme has been considered the best or least desirable. The most common and generally accepted system of PM is the periodic interval system or calendar based. However, this system has a number of weaknesses.

To overcome some of these shortcomings, the usages based system has certain advantages. Implementation of such a system involves more precise data collection requirements and direct interaction with the process and equipment. It is necessary to make a judgement whether the advantages of such a system outweigh the possible difficulties of implementation. Only a complete evaluation of the operation of the two schemes could develop such an answer. A practical evaluation of the two schemes from a real-world installation would be time consuming and difficult to complete. A simulation model developed around a real-world situation to perform this function would provide the data to adequately evaluate both systems. The simulation model developed in this thesis provided the data to make valid judgement of the merits of one system over the other.

The model output data showed significant differences in manpower utilization and equipment performance in favor of the usage based system. It was found by keeping the manhour parameter constant

and operating the model in both modes of PM, the data showed up to .6% gain in productivity when the equipment was monitored for the usage based system. For a large operation this represents a significant increase and would justify the establishment of such a program.

CHAPTER I

BACKGROUND

Maintenance Management systems from the simplest to the most complex forms have been applied in all types of industry and service institutions. No one system has been considered the panacea for all to follow. The systems that rely on completely manual record keeping, planning, scheduling and accounting are acceptable if the operation is small. The more advanced systems designed for larger operations employ computers that include maintenance in the "Management Information System". These systems handle not only the record keeping and accounting but provide data that also assists in decision making. These advanced systems of Maintenance Management, however, do not always fully extend to the area of planning and scheduling.

In a period of escalating material, services, and labor costs, it is obvious that attention to maintenance costing and cost improvements would appeal to plant managers. The objective is to apply effective management to gain control of the maintenance situation. Any number of possible approaches can be employed. One approach applies the techniques of the management process to develop a maintenance system that fits the needs of each specific operation. The system must be designed and operated within an established budget to verify the overall effectiveness on the operation under control.

The systems discussed throughout this thesis exist within categories defined as non-integrated, partially integrated, and fully integrated. The non-integrated system operates with no computer assistance. Under this system record keeping, work initiative and reporting is done manually. The chart illustrated in Figure 1 has been prepared to make a comparison of a non-integrated system with a proposed fully integrated system in every aspect of the management process. The partially integrated system uses a data processing computer to supply record keeping, back up maintenance information, periodic work schedules and performance reports. The fully integrated system utilizes both a data processing computer system and one or more process control computer systems. The process control system is data linked to the data processing system for feedback purposes. In this system maintenance of equipment controlled by the process control computer is enhanced by operational data and performance information supplied to the data processing computer. The fully integrated system contains all the benefits of the partially integrated system plus the ability to perform more timely maintenance services to provide more efficient control of manpower and to collect more accurate equipment operation information. The chart in Figure 1 points out the differences between maintenance systems operated at both ends of the spectrum of sophistication. In actual practice, each new maintenance system must be examined within its operating environment to determine what level of sophistication is required. All maintenance systems are not operationally or economically feasible to operate in a fully integrated mode.

MANAGEMENT PROCESS ELEMENT	NON-INTEGRATED	FULLY-INTEGRATED
Objectives:		
Short Term (Tactical)	1. Minimize daily production losses via repairs. 2. Complete scheduled daily activities. 3. Project daily work requirements.	1. Minimize daily production losses via repairs. 2. Complete scheduled daily activities. 3. Project daily work requirements. 4. Adjust daily activities if operating schedule changes. 5. Operate PM system. 6. Measurement.
Long Term (Strategic)	1. Lower overall maintenance cost. 2. Eliminate chronic problem. 3. Improve maintenance techniques. 4. Improve equipment 5. Keep accurate records.	1. Lower overall maintenance cost. 2. Eliminate chronic problem. 3. Improve maintenance techniques. 4. Improve equipment. 5. Balance work distribution to minimize manpower. 6. Keep records. 7. Maintain data base of specific historical information about all equipment in an optimal form.

FIGURE 1

Chart of Management Objectives Relating to Non-Integrated and Fully-Integrated Maintenance Systems.

MANAGEMENT PROCESS ELEMENT	NON-INTEGRATED	FULLY-INTEGRATED
Planning:		
Best advanced schedule of specific jobs	One shift ahead	Twenty shifts ahead
Best advance schedule of PM	Day shift only	All operating shifts
Explicit details of work	Sketchy	Specific check list of work sequence
Backup information (device historical record)	None or sketchy	Complete device engineering records
Scheduling:		
Advance manpower required for specific jobs PM and breakdown	One or two shifts	Twenty shifts
Availability of equipment	None forecasted	Forecasted on weekly schedule adjusted daily
Ability to handle change in operating schedule	Difficult to handle manpower wise	React with manpower reassignment accordingly

FIGURE 1 (Continued)

MANAGEMENT PROCESS ELEMENT	NON-INTEGRATED	FULLY-INTEGRATED
Execution:		
Supervisory responsibilities.	1. Oversee work. 2. Review schedule. 3. React to changes. 4. Order repair parts, tools, and new operating equipment.	1. Oversee work. 2. Review schedule. 3. React to changes. 4. Order repair parts, tools, and new operating equipment. 5. Update data base.
Feedback:		
Report time. Report date. Report job duration. Report problems. Report solution. Report PM Completion items. Report delays.	No formal documents. Existing information is difficult to relate to tasks.	System receives this information for productivity analysis, PM records and data base maintenance.
Control:		
Compare with schedule. Generate exception reports. Exceptions to incomplete PM schedule. Stand exception reporting procedures.	No reports generated.	System produces appropriate exception reports.

FIGURE 1 (Continued)

A wide variety of maintenance costing and accounting systems befitting different operations are currently available. Therefore, finding a universally accepted cost system is extremely difficult. If every hour of maintenance time is assigned by a work order number then cost allocation is infinitely easier than a system where maintenance personnel time is charged to a general shop overhead account. In the latter instance the daily activity and productivity of the maintenance man escapes easy and accurate measurement.

Justification of the installation of new equipment for a computerized "Maintenance Management" system based on benefits of manpower and parts inventory control could fall short on typical payback schedules. However, if the major capital items such as the data processing computer and data collection facilities are already in service for other accounting and management functions the justification appears more attractive.

The more sophisticated the requirements for the maintenance system are, the more stringent the data collection requirements become. Conventional computerized maintenance systems at most employ data terminals or card input for updating the host computer. The timeliness of the input data affects the accuracy of the entire system especially if the system is planned to react immediately to changes. Any significant changes of an operating nature dictate schedule changes for preventive maintenance, major rebuild activities or daily shift assignments.

In order to meet the timeliness and accuracy of the data requirements, a second computer, collecting data on a real time basis at the shop level, linked to the host computer is required to handle the problem. If the second computer actively participates in control of the shop operations it should already contain the data needed by the host computer to perform the maintenance management functions. This second computer then becomes a process control computer.

The process control function with computers has been a rapidly expanding application of the computer. Early applications involved very dedicated control of a small portion of a given industrial control system. Gradually as technique and technology progressed, the process control computer encompassed an entire control system by monitoring and controlling many interrelated elaborate devices. These areas of control include Steelmaking, Power Generation, Mass Transit, Chemical Production, Warehousing and numerous other applications. The parameter common to all these applications is "real time". Each of these systems must deal in "real time" to successfully achieve the desired output performance.

The great trend toward management information systems readily lends itself to the process control computer. The process control computer, as it is being applied in the case under study, contains information that if properly retained and formatted can be used as input to an information system without the intermediate step of manual handling. The most significant advantage is the timeliness of the information. Under current applications in which manufacturers of finished products are concerned, very relevant quality control information can be transmitted piece by piece or batch by batch depending on the user requirements.

Embedded subtly in the process information are the data whereby the maintenance of the process equipment and control equipment can be monitored and directed. Once this step is achieved the evaluation of maintenance personnel can be ascertained. Needless to say the process control computer cannot do this on its own. This type of computer has the prime responsibility to the process and it is not designed to handle major data processing type functions.

It is proposed that the host data computer linked to the process computer handles the rough task of data compilation and forms generation. The entire concept is based on eliminating the lost time in formulating production feedback to a given information system through shop terminals. In many processes, the process control system already contains much of the data that is also fed back to the host computer through a separate shop terminal. However, in many cases that information is lost as the next series of orders is processed. Presently, if an information system is tied in to the process control computer, it does not consider the aspects of the productivity of the maintenance personnel servicing the system control equipment.

With the continuous effort toward creating real time information systems, the capability of linking with process control computers with data processing computers is rapidly being developed. The area of study proposed is to investigate systems whereby the process information is used to schedule, control and manipulate preventive maintenance procedures and to measure the productivity of those performing the overall maintenance functions and to compare such systems with those not employing such information.

Maintenance functions have historically been relegated into after-the-fact systems. A good universal system has not been defined. The one fact agreed to is that maintenance costs are real. The maintenance dollar is a very significant cost factor of a production facility. Yet, the effectiveness of the maintenance dollar has been elusive and rarely definable. It is, however, a major contribution to profitability. Some maintenance expense is essential. This investigation provides a means to determine if scheduling preventive maintenance on an equipment usage basis is a more effective usage of the preventive maintenance dollar than the calendar based preventive maintenance scheduling system.

The day to day output of maintenance personnel is difficult to equate in many kinds of production facilities. However, when a sophisticated order entry process control and production reporting system is applied there could be also a system to schedule preventive maintenance and to measure productivity by using the data that are already available. The proposed system gives the added feature of productivity measurement without extra data collection personnel.

The preventive maintenance function is to be applied to mechanical, electrical and electronic equipment including the computer or computers themselves.

CHAPTER II

PROBLEM STATEMENT

Historically, maintenance in the industrial atmosphere has been accepted as a necessary evil. When times are good, maintenance costs are eventually ignored as are the activities of the craft personnel. Machines and controls are serviced on a breakdown basis only. As operating costs creep upward and orders fluctuate radically, maintenance expenditures with respect to their influence on profits, become more apparent. It is very obvious that a better handle on the maintenance function is required.

The initial steps to improvement included streamlining record keeping systems and developing preventive maintenance schedules which were used to inspect and lubricate mechanical equipment, and to inspect, tune and clean electrical or electronic equipment. These schedules, repeated on a periodic basis, resulted in a definite improvement in the service of the equipment. As more and more shops were included in this maintenance system, paperwork increased tremendously. Both the record keeping system and updating procedures required dedicated personnel. The next logical step was to streamline the records and scheduling system by storing the data in computers; permitting the schedules to be issued by the computer and records kept by the computer. The records input data into the computer would be through cards or other media. This input data contained the completion data about the schedules the computer issued for the previous inspection period.

So, wherein lies the problem? The fact is we must be able to develop a sufficient knowledge of maintenance activity to assist us in forming a well organized and meaningfully controlled maintenance department. This organization must be developed so that its members, maintenance personnel, are made aware of their effect on production and profitability. To achieve this end, more than just a periodic schedule for preventive maintenance is required. The function must be extended to include historical records of repair on equipment, cost expenditures on a given machine, standards for maintenance job times, distribution scheduling and other maintenance oriented details. The literature on such advanced systems is sparse. More development in this area is required.

James K. Hildebrand in his book Maintenance Turns to the Computer,[1] describes an example of a partially integrated system of maintenance control using a data processing computer. Mr. Hildebrand's maintenance system involves preventive maintenance and prescheduled work, backlog work and call-in work. Mr. Hildebrand's preventive maintenance system calls for establishing inspection intervals in time. These times are based on the risk of downtime on a given machine. After a period of time, the historical repair record of a

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(1) Cahner Books, Boston Massachusetts, 1972.

machine may be reviewed to determine if trends in repairs indicate reducing or increasing the inspection interval. The computer designates a work order number to each job assigned. It then waits some prescribed time then lists a "back-log" for any job work order number it has not received a completion card as feedback input. Thus an exception report. Breakdowns are classified as call-in work and inputs to the computer are coded to be reflected in the equipment historical record and cost control records.

Mr. Hildebrand's system, and other similar to it, may be excellent in the environment in which they are applied. Those applications include machine shops, foundries, job shops, assembly plants and many other types of production shops. These types of computerized maintenance systems nevertheless still lose sight of two factors. The first area of omission is the day to day productivity of the man responsible for breakdown maintenance. This man holds the assigned maintenance position. This position relates to the men who are scheduled to work on operating shifts and repair all breakdowns as they occur. We are presently able to determine the output of men whose sole concern is to handle scheduled maintenance. It is the performance of the assigned maintenance man that has been elusive to adequate measurement. The second deficiency is in the method of establishing the interval of inspection listed on preventive maintenance schedules. Most preventive maintenance schemes use established time intervals in weeks, months, or days as triggers for work schedules. These schedules are totally ignorant of whether the machine or whatever being inspected, tuned or lubricated has even been in service during any, most, or all of the time since the last inspection. These schemes keep maintenance personnel busy, but not necessarily productive. There seems little sense spending time inspecting, tuning, or lubricating or tightening some piece of equipment that may have only been in service part of the time after the last work order appeared on the preventive maintenance schedule.

For example, with today's rising costs in petroleum products, there is nothing gained from regreasing some piece of equipment or changing virtually unused hydraulic oil and filters if the machine only had token service. This type of situation can easily occur in the larger organization where the maintenance force is so large that the man doing the job may not always work in the same area or section where the machine is located. Unless proper information is made available, he does not know that this machine has not had orders and was out of service three-fourths of the time since work was previously performed on it.

It should be noted that the reverse situation can also occur. This happens when the supervisor trend review shows inactivity on some machine and the preventive maintenance schedule is then lengthened. Then, if orders are received and this same machine goes back into high production, problems can arise because the preventive maintenance cycle is too long. This situation can develop if nothing is changed on the preventive maintenance schedule until the next trend review period. The standard scheme cannot adjust to these situations until the scheduled supervisor trend review makes the change manually. This is because there is no present mechanism in the system to record in the computer on a real time basis the actual production hours of a given piece of equipment.

We are looking for the mechanism that can track the production status of equipment on a real time basis and at the same time collect data required to measure the productivity of maintenance service personnel. The mechanism to achieve the desired results resides in a process control computer system. However, the process control computer system cannot act alone. It must be supported by a large data processing computer. The process control computer collects the data in a "matter-of-fact" manner because in most cases some form of the data are used to run the process. The problem is to be aware that the data are there and to format it properly for transmission to the data processing computer along with the normally scheduled data transmissions.

Data collection has always been a difficult problem for overseeing the day to day activity of maintenance personnel. This proposed system not only performs the tedious data collection activity, but also eliminates the step of manually preparing the data collected for input to some computer system or manual incentive system.

The types of manufacturing or production organizations that lend themselves to this approach are the automated machine shop operating under direct numerical control as depicted in Figure 2 and manufacturing processes that are process computer controlled, such as metals, paper, glass, chemical or other production complex as shown in Figure 3. The production complex would include raw material handling, manufacturing, finishing and secondary processing (if required), product storage and product shipping.

The amount of investment in equipment in such a complex warrants efforts to establish a meaningful preventive maintenance program. Nor must one overlook the additional problems of effective staffing of maintenance personnel and effective scheduling of maintenance activities. The problems of staffing and scheduling go hand in hand with productivity. For example, if a method of effective measurement were established and work scheduled around the clock using assigned shift personnel, equipment that would normally be serviced on a day turn could be completed on off shifts.

The term "assigned maintenance man" previously mentioned is further defined as groups of service people assigned to maintain a production unit. The primary function of these people is to repair electrical, electronic, mechanical, hydraulic and all other service oriented breakdowns as needed on operating turns. Their work time is charged against the production shop and normally does not reflect the work assignment for that shift. The practice in the past for this type of maintenance operation has been to schedule minimal

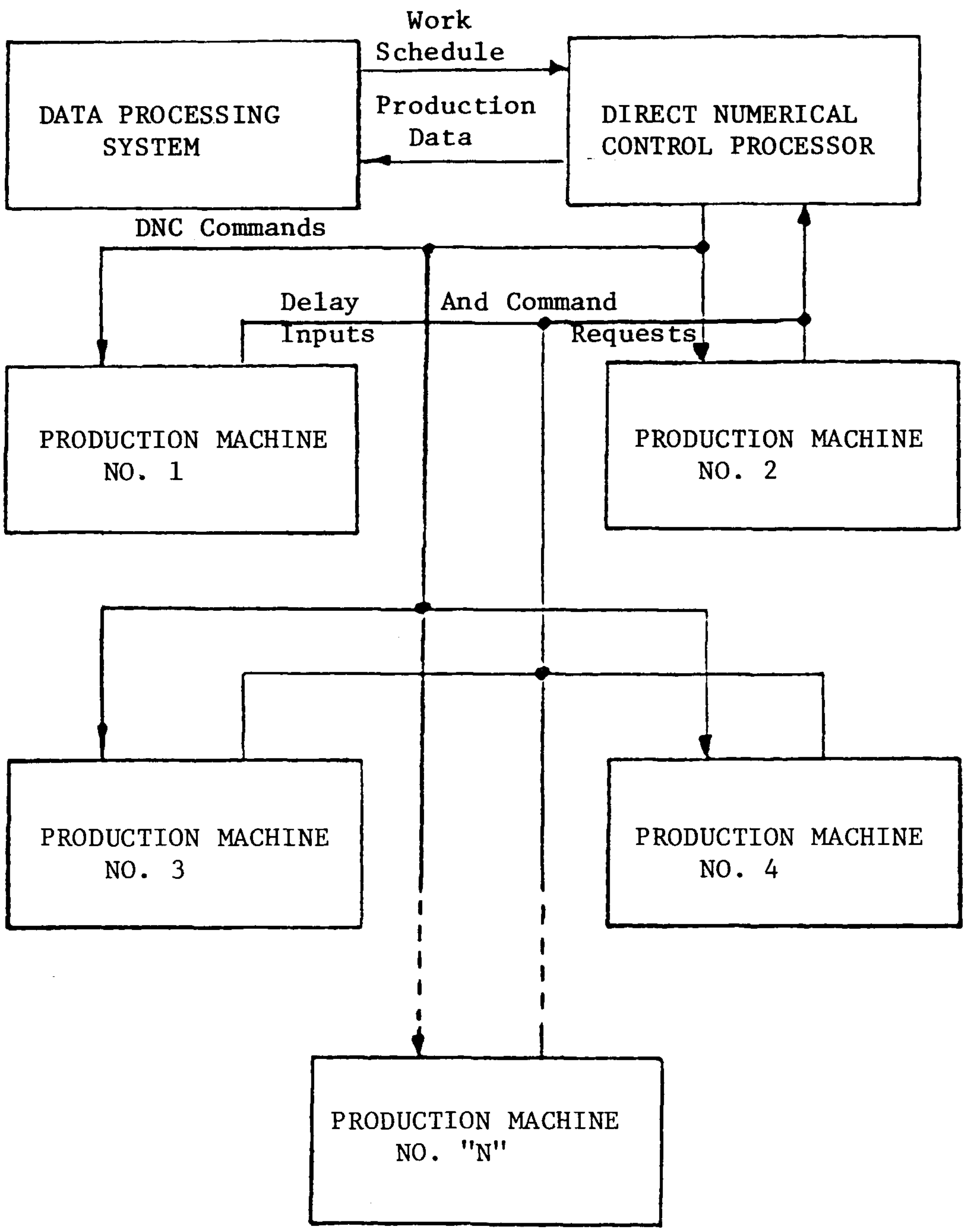
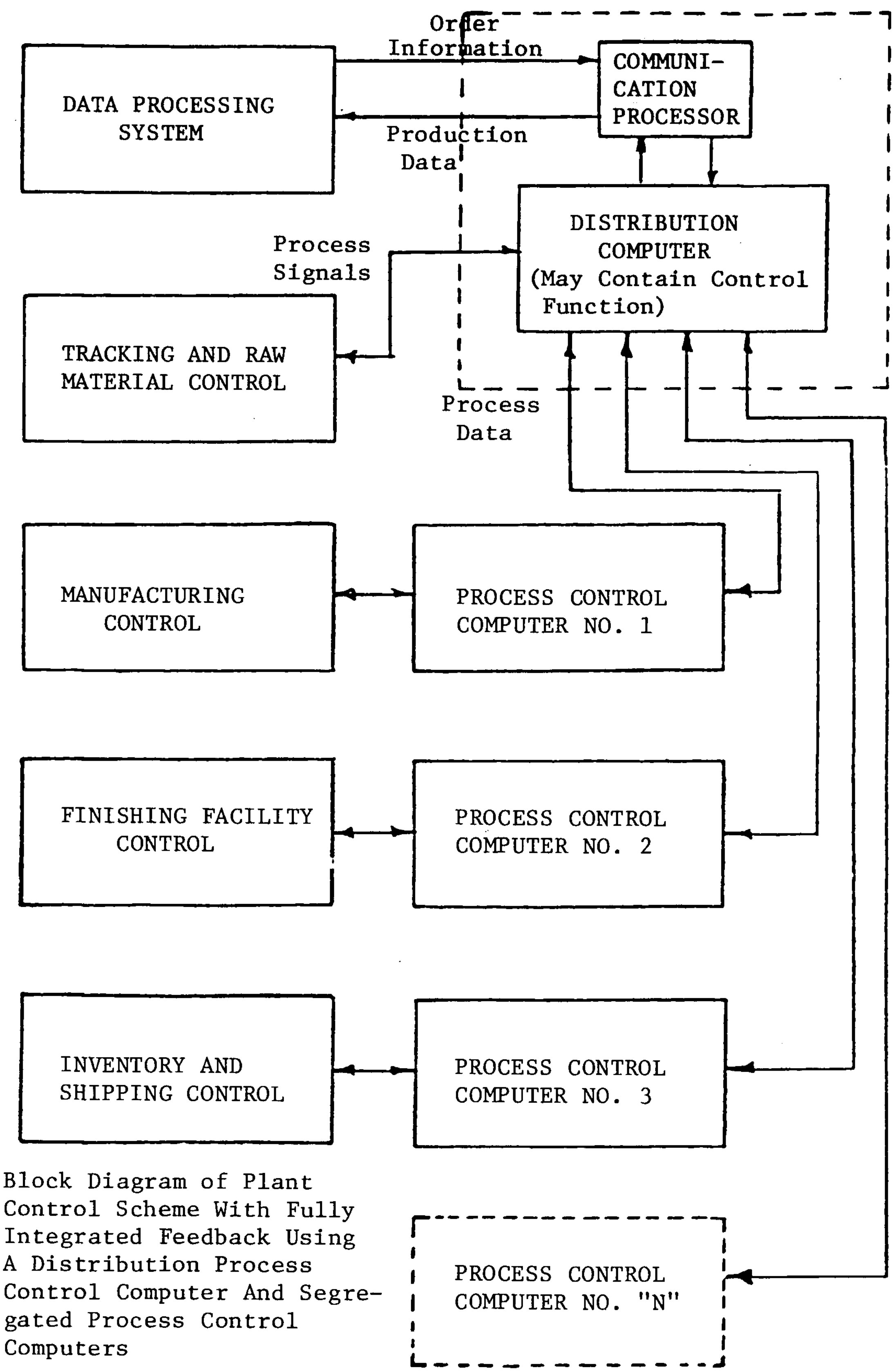


FIGURE 2

Block Diagram of Shop Control Scheme With Partially Integrated Feedback Using Direct Numerical Control



Block Diagram of Plant Control Scheme With Fully Integrated Feedback Using A Distribution Process Control Computer And Segregated Process Control Computers

FIGURE 3

personnel on non-day shifts. These personnel are primarily concerned with performing breakdown maintenance and small jobs that can be completed or left undone if a breakdown should take up most of the shift. On the day shift, more personnel are scheduled to work. These people normally handle large jobs and preventive maintenance. More supervision is also available on day shift to monitor the activities of those performing assigned jobs. We must be able to judge whether we are making effective use of the non-day shifts. There is a good possibility that some equipment used on day shifts may be available on the other shifts for preventive maintenance work or a major rebuild that if done on a day shift, could slow down the production cycle.

This is leading to evidence of the need for effective use of maintenance personnel with the production requirements of the manufacturing complex. The key elements for success are effective day to day personnel activity measurement and day to day update on the usage of the production equipment.

The proposed solution to be investigated that will satisfy these needs also can incorporate record keeping and cost control data on equipment expenditure. These features were included with the system described by J. K. Hildebrand. It is not the purpose in this thesis to include these features, since we know they can be done. The ojbective here is to investigate the possibility of moving industry one step closer towards effective maintenance by adding the dimension of real time to the reporting function at minimal costs. More effective maintenance can be achieved by using the personnel more productively and performing preventive maintenance of equipment by actual production hours. Using actual operating hours is a new approach to preventive maintenance.

The area of investigation then is to take a system that includes one or more process control computers data linked to a host data processing computer and to use the process-generated information in conjunction with the host computer to operate a preventive maintenance system and measure the productivity of the personnel involved. This new fully integrated system can be compared with a partially integrated maintenance system. Various operating measures will be used as criteria for evaluation.

The chart in Figure 4 lists the attributes of the two systems under investigation. Specific concentration will be placed on the areas that appear to have the most significant overall affect on the parameters considered for the evaluation in the chart.

MANAGEMENT TECHNIQUES	PARTIALLY INTEGRATED	FULLY INTEGRATED
Objective		
Short Term (tactical)	1. Minimize shift production delays. 2. Complete schedule shift activities. 3. Project work requirements. 4. Operate PM system (based on fixed intervals).	1. Minimize shift production delays. 2. Complete schedule shift activities. 3. Project work requirements. 4. Operate PM System (based on actual operating hours). 5. Adjust shift activities as operating schedule changes. 6. Measure worker activities.
Long Term (strategic)	1. Lower overall maintenance cost. 2. Eliminate chronic problems. 3. Improve maintenance techniques. 4. Improve equipment. 5. Keep accurate records.	1. Lower overall maintenance cost. 2. Eliminate chronic problems. 3. Improve maintenance techniques. 4. Improve equipment. 5. Keep accurate records. 6. Provide accurate specific information about all equipment. 7. Balance work distribution to minimize manpower.

FIGURE 4

Chart of Management Objectives Relating To Partially Integrated and Fully Integrated Maintenance Systems.

MANAGEMENT TECHNIQUES	PARTIALLY INTEGRATED	FULLY INTEGRATED
Planning		
Best advanced schedule of specific jobs	Three Shifts (1 day) ahead.	Twenty-one Shifts (7 days ahead.
Best advanced schedule of PM	PM System lists items to be worked on but not availability.	PM System lists items to be serviced and the shift available up to 21 shifts in advance.
Details of work plan	Sketchy to accurate depending on the advance notice.	Specific check list of work sequence.
Backup information (drawings, parts data, mechanical and electrical data)	Sketchy.	Complete device engineering records. Device includes control equipment and machinery.
Scheduling		
Advanced manpower requirement for specific jobs and PM	One shift ahead (1/3 day).	Twenty-one shifts (7 days) ahead.
Availability of equipment.	Not forecasted.	Forecasted on a weekly basis and adjusted daily.
Ability to adjust changes in operating schedule	Difficult to reassign manpower.	Assign manpower according to demand.

FIGURE 4 (Continued)

MANAGEMENT TECHNIQUES	PARTIALLY INTEGRATED	FULLY INTEGRATED
Execution		
Supervisory responsibilities.	1. Oversee work. 2. Review schedules. 3. React to changes. 4. Handle feedback to records system. 5. Handle PM scheduling according to lists. 6. React to breakdown. 7. Minimize production delays. 8. Maintain inventory.	1. Oversee work. 2. Review schedules. 3. React to changes. 4. Handle feedback to records system. 5. Handle PM scheduling according to lists. 6. React to breakdown. 7. Minimize production delays. 8. Maintain inventory (can be computer function).
Feedback		
Report time Report date Report task duration Report problems Report solutions Report PM completion items Report delays	1. Complete PM records. 2. Report other items through manual record keeping. These are difficult to summarize.	1. Complete PM records. 2. Process computer supplys remaining data to host computer. 3. Every shift full complete and timely information available.
Control		
Exception reports to incomplete PM work	Reports generated by PM System.	Reports generated by PM System.
Delay performance report	Reports not generated.	Output by host computer for management purposes.

FIGURE 4 (Continued)

CHAPTER III

PROPOSED SYSTEM DESCRIPTION

Keeping in mind the output requirements of the system as described in the previous chapter, presented here is a system design and description to achieve those requirements. Before delving into the ramifications of the proposed system, a discussion of the design philosophy is desirable.

Regardless of how they may be described in the trade literature and books, maintenance organizations peculiar to the older metals industry have little use for any preventive maintenance system that takes too much clerical time. If any automated reporting or scheduling system is to be successful, it must be skillfully designed to contain as little paperwork as possible with the highest effective information content. Oftentimes, a corporate edict is generated requiring the installation of some production, maintenance, inventory control, safety, or other program. Unfortunately the burden of the program nearly always falls on the line supervisor, who is already deluged with forms for time, safety, quality, inventory, grievances and numerous other needed programs. Aside from filling out these forms he is above all responsible for the activity of his subordinates, the production or maintenance employee. Therefore, a primary object of any new system should be to accomplish the job by avoiding additional work or by reducing existing paperwork. This can be achieved by making the new system a tool that the overburdened supervisor wants to use in his daily routine. Thus, the objective is to design a system that is used by the supervisor and not a system that uses his time inefficiently.

The output reports of many of these systems are fine, but the input requirements put the burden on the first-line supervisor which may be the wrong level of supervision for this. The position must be taken that output reports can be anything one may want, but to generate these reports let the data processing computer manipulate more data than usual. The raw input from the shop could be in a less organized form. The approach philosophy must be toward freeing the line supervisor to pay more attention to production or maintenance. Most of these line supervisors are promoted from the ranks of the craft they are supervising. They are trained as craftsmen and not skilled managers. It is therefore obvious that we must design the systems as suitable tools for their use without jeopardizing the time they must spend overseeing activities whereby they can best assert this influence toward profitability. The system described in the following paragraphs, attempts to provide such a tool without interfering with his main functions as a line supervisor.

As indicated, both process control and data processing computers are required for success of this type of application. The data processing computer does the non real time activity of record keeping, report generation, schedule generation and data base maintenance.

The process control computer collects real time data related to requirements of productivity measurement and preventive maintenance scheduling. The productivity measurement depends on the quality and effectiveness of the preventive maintenance system. Accordingly, the preventive maintenance system description is what will be discussed first.

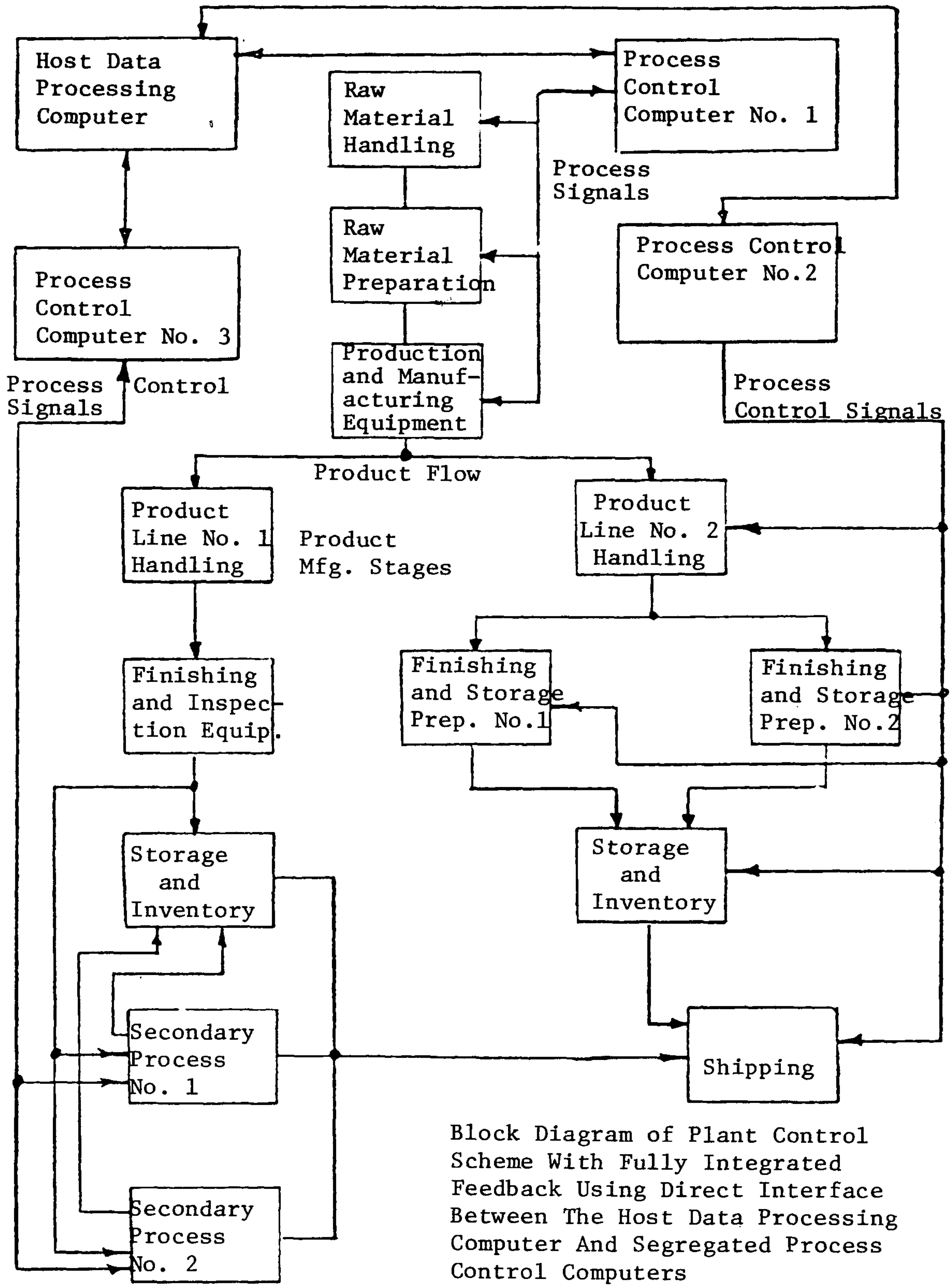
The preventive maintenance system has as its basic and unique ingredient the actual service production time of a given piece of equipment. It is designed around groups of area subsystems. The area subsystems of a manufacturing complex employed as a prototype for this system are as follows:

1. Raw material handling.
2. Raw material preparation.
3. Product manufacturing equipment.
4. Product line No. 1 handling equipment.
5. Product line No. 1 finishing and inspection equipment.
6. Product line No. 1 storage and shipping equipment.
7. Product line No. 1 secondary process No. 1 equipment.
8. Product line No. 1 secondary process No. 2 equipment.
9. Product line No. 2 handling equipment.
10. Product line No. 2 finishing and storage preparation line 1.
11. Product line No. 2 finishing and storage preparation line 2.

12. Product line No. 2 storage and shipping equipment.

Figure 5 shows the schematic of the area subsystems and computer interaction. The need for the breakdown of the complex into these area subsystems is two-fold. First, the process control computer control assignments have a minimum amount of overlap with this configuration. Thus, the data collection assignments are easier. Secondly, when operating various product mixes the equipment within an area subsystem operates as a unit making production hours reporting easier. Using large area subsystems will on the whole reduce the data processing update time for most products. However, some of the products manufactured require special coding of the information about some areas subsystem. This coding is to be done in such a way that during the data processing update phase certain flags cause a further breakdown, within these special area subsystems, to take place internally to the data processing computer.

Let us discuss the sort of data base required to support this system. Building the data base is the most tedious phase in the installation of any maintenance system. If this system were applied right from the installation of the complex all the information would be readily available and building of the data base would be quickly completed. On the other hand, as usual, initial budgetary priorities defer an automated maintenance system until a much later date - if at all. This usually means when a system is finally installed, building of a data base could be a burdensome task if the manual system



Block Diagram of Plant Control Scheme With Fully Integrated Feedback Using Direct Interface Between The Host Data Processing Computer And Segregated Process Control Computers

FIGURE 5

being used had been well kept up or else had been totally non-existent.

The requirements of data base construction include means of data acquisition and a means of changing the known data. To achieve simplicity the system must have a minimum amount of input formats. What's needed is one universal input format sheet for use by both mechanical and electrical personnel, which can be used to add or change information in the data base. The electrical equipment will include normal electrical equipment and control and the electronic equipment and control (including the process control computer). The mechanical equipment must also be subdivided to consider hydraulic requirements as well as lubrication requirements. The following items are required as input on each piece of equipment in the system:

ITEM RECORD

1. Area subsystem No.
2. Device No.
3. Mechanical PM hours.*
4. Lubrication PM hours (mechanical equipment)*
5. Motor lubrication PM hours.*
6. Control PM hours.*
7. Motor PM hours.*
8. Location on grid.
9. Description of item.
10. Function of item.

11. Check list Nos. - electrical and mechanical. (related to each item 3 through 7)

12. Mechanical drawing Nos.

13. Hydraulic fluid No. (if applicable).

14. Lubricant name and No. (if applicable).

15. Motor data.

16. Motor drawing Nos.

17. Motor control data (voltage phases electrical control or electronic control location).

18. Control scheme drawing Nos.

19. Control scheme reference manual Nos.

20. Job safety analysis No. (mechanical and electrical).

* Service code on work feedback card points to which service is to be performed.

These items listed fulfill the informational needs of the fully integrated system. Each item in the system will be identifiable by the first two numbers of the Item Record, Area Subsystem No. and Device No.. Each field will be assigned the same definition for all items. Therefore, the input format document need only contain the two identifying fields, the number of the field to be changed and the changes to be input. This input/output format for the system data base may in the final analysis require more vigorous programming effort but this is the sacrifice to be paid for a less cumbersome system from the user standpoint. The analyst and programming costs may be higher. This is a one time cost as compared to wasting the user's time on a daily basis.

In treatment of this subject references will be made for use of formats and program requirements of the supporting data processing system. These statements are of a general nature and do not consider all the details or specifics of a finely tuned management type information system. This presentation shall be limited in detail to those areas that are pertinent to the objectives of this thesis. The only desire here is to investigate the ability to make the proposed comparisons.

It is necessary here to elaborate about the system input data so that its relevance to the overall system can be understood. Although the primary purpose of this thesis does not require detailing every aspect of the design of a preventive maintenance system, an outline knowledge of the proposed usage base system operation is necessary to establish whether the results of productivity measurement and actual production hours preventive maintenance intervals are more successful than present approaches. A description of each input field mentioned in the Item Record follows:

1. Area Subsystem Number

   As previously mentioned the equipment in the complex that most normally functions as a unit will be grouped together. The purposes of this grouping is to make recordings of data by the process control computer a more unified approach. This number will require three numeric characters.

2. Device Number

This number is four digits and identifies a specific piece of equipment in an area subsystem.

3. Mechanical PM Interval Hours

This four digit number signifies the number of operating hours required between mechanical service intervals.

4. Electrical or Electronic Control PM Interval Hours

This number defines the number of operating hours between preventive maintenance.

5. Motor PM Interval Hours

This number defines the number of operating hours between preventive maintenance service calls.

6. Lubrication PM Interval Hours

This number defines the number of operational hours between mechanical equipment lubrication. This will always be a multiple of the inspection interval.

7. Motor Lubrication PM Interval Hours

This number defines the number of operational hours between motor bearing lubrication. This will always be a multiple of the inspection interval.

8. Grid Interval Location

This four character alpha numeric designation identifies the location on the manufacturing complex plan map where the piece of equipment is used.

9. Description

This is a brief description of the piece of equipment such as cylinder, transmission, coiler, shear, transfer, etc.

10. Function

This title is used to briefly describe the use of the piece of equipment in the system.

11. Check Lists Numbers

This is a four character alpha numeric designator. One alpha followed by three numerics define the list of items to be checked during a scheduled preventive maintenance service call on a unit in an area subsystem. The alpha is an "M" or "E" for Mechanical checklist or Electrical checklist. There is a checklist for each service required as defined by the service code pointing to items 3 through 7 of the Item Record.

12. Mechanical Drawing Numbers

This field contains space for key engineering drawing numbers. The complete set of engineering drawing numbers that define the mechanical device are output in the information document section of the system which need not be defined here.

13. Hydraulic Fluid Number

This field defines the recommended hydraulic fluid.

13. Hydraulic Fluid Number (Continued)

If no fluid is required the field is blank.

14. Lubricant Number

This field contains the lubrication department's number for the lubricant required on the unit described.

15. Motor Data

This entry contains information on the required motor or motors for the application described. Motor Data includes frame number, voltage, frequency (OHZ = DC), number of phases, full load current, lubricant number and carbon brush number.

16. Motor Drawing Numbers

This field contains space for pertinent motor engineering drawing numbers. The complete set of engineering drawing numbers that define the motor output in the information document section of the system which need not be defined here.

17. Control Data

This data defines the type and location of the starter or regulator supplying power to the motor defined above. If no motor is involved this data defines the control device such as computer, static logic director or servo control.

18. Control Scheme Drawing Numbers

This entry lists the number of the engineering drawings containing schematics and wiring diagrams of the control described in the previous entry.

19. Control Reference Manuals

This entry lists the control manufacturer's design numbers associated with the control device defined under the given unit number.

20. Job Safety Analysis Numbers

This is a four character alpha numeric designator. One alpha followed by three numerics define the number of the document which describes the safety procedures to be followed during a scheduled inspection. The alpha defines "M" for Mechanical and "E" for Electrical.

As previously mentioned some basic data for the preventive maintenance resided in the host computer. This data and information essentially revolve around the production schedule forecasting. This forecast is the schedule of products to be manufactured and product lines to be operated on a forecast basis one week in advance. The schedule is reforecast on a daily basis as a result of actual production figures. (In a later description of the preventive maintenance system operation it will be shown how the daily reforecasting will not drastically affect the preventive maintenance schedule for any given week.) Using the production schedule and stored data describing which area subsystems are to be operated for each product, a schedule of equipment to be used each shift is easily generated. This ultimately will be used to complete the weekly preventive maintenance work schedule.

As mentioned in the early part of this discussion, the bulk of the data collection job is assigned to the process control computers. The data from the process that is required to support this system are confined to a few areas. The data consist of the manufacturing delays each shift, production, processing and shipping information each shift. When a process control computer is used, its normal operation can and does in the prototype used here incorporate a utilization function. The utilization function measures expected times between events in the process. When the fixed times are exceeded a program records the time. While the process continues it asks for an input delay reason code from the shift supervisor through a CRT terminal or other input device. These delays are summarized at the end of a shift and sent to the host data processing computer for report generation or use as data for systems such as this one. In the prototype system there are three process control computers controlling equipment in the areas described previously as subsystem areas. The control algorithms in the computers record the number of operations performed by the equipment being controlled. Also included as a side benefit of the process control function, the computer tracks each manufactured piece through the system, passing pertinent information about a product from one computer to another as the product passes into the area of control of a given computer. As a result of this function, inventories and shipping records are accurately updated. This production information is also summarized and returned to the host computer giving results of the productivity of each area subsystem on shift basis.

With the host computer now containing delay information, actual shift production, stored bogey figures, production schedules and equipment operating schedule, the equipment usage tables can be updated and maintenance productivity information is closer to reality. With the basic information sources outlined, an explanation of the fully integrated preventive maintenance system now becomes more meaningful. This system will be set up on a weekly schedule. The data processing computer will generate the information for a week from Sunday to Saturday by the previous Thursday afternoon. The data processing computer will use the procedures outlined below to ready the documents for a new week. A set of documents will be generated for the mechanical supervisor and the electrical supervisor.

1. The supervisor will return the Work Feedback Cards for the previous week to the data processing center. This will cause an update of the records. In all cases the computer subtracts only the hours listed on the feedback cards from stored data. This allows for accumulation of

operating hours added since the Work Feedback Card was issued.

The system is designed to retain records of which Work Feedback Cards were issued. After the update is completed a search of the cards returned is made and the outstanding cards are flagged for listing in Exception Report No. 1

2. The computer will use forecasted production schedules to determine what equipment is to be idle on all shifts in the next week.
3. The host computer will determine which pieces of equipment from Step 2 have equalled or exceeded the inspection interval of actual operating hours.
4. The host computer will determine which pieces of equipment (if any) scheduled for operation have equalled or exceeded inspection interval. These items are an exception to the system.
5. The host computer will produce Work Feedback Cards for the equipment found in Step 3 above.
6. The host computer will produce a printed list of the equipment for which the cards were issued in Step 5 with the data and shift projected for the equipment to be idled.

7. The host computer will produce Exception Report No. 1 consisting of a list of Work Feedback Cards not returned and the date issued.

8. The host computer will produce Exception Report No. 2 consisting of the list of items found in Step 4. These are items that require servicing but have not been scheduled down. If service is performed on any item on this list, a Work Feedback Card can be filled out and submitted through normal procedures.

The formats of the documents shown in Steps 6, 7 and 8 above are shown in Figures 6, 7 and 8.

Every Thursday the maintenance supervisors each receive the three reports and a deck of Work Feedback Cards for the next week. They can now plan their work assignments for all shifts for the next week. Since the projection of the production schedule may not remain completely accurate job assignments cascade from one shift to another as required. This system of cascading assignments as the equipment becomes available highlights one of the advantages of the preventive maintenance system. By having a minimum quantity of preventive maintenance personnel on all shifts all pieces of equipment will be serviced when the assigned interval expires. This contrasts to having a high number of preventive maintenance personnel on possibly a day shift only. However, the equipment that is to be serviced in these shift operations may not be available on day shifts when inspection intervals expire.

WEEKLY PM WORK SCHEDULE

AREA NO.	UNIT NO.	DATE AND SHIFT SCHEDULED

FIGURE 6

Maintenance Weekly PM
Schedule Format

EXCEPTION REPORT NUMBER 1

OVERDUE WORK FEEDBACK CARDS

REPORT DATE ____________________

AREA NO.	UNIT NO.	DATE CARD ISSUED

FIGURE 7

PM System Exception Report No. 1 Format

EXCEPTION REPORT NUMBER 2

UNITS EXCEEDING PM INTERVAL HOURS BUT
NOT SCHEDULED IDLE IN THE COMING WEEK

REPORT DATE ____________________

AREA NO.	UNIT NO.	INTERVAL HOURS	ACTUAL SERVICE HOURS

FIGURE 8

PM System Exception Report No. 2 Format

It is expected that personnel on all shifts participate in preventive maintenance work and, therefore, as long as there are no breakdowns or other failures, the assigned maintenance man must help the preventive maintenance man scheduled and vice versa.

It is obvious that the two reports and the Work Feedback Cards are not all that is required by the maintenance personnel to perform the actual PM work. This brings up the Document Section requirements of the Data Processing System. It should be emphasized that the equipment data retained by the data processing system remains in storage until changed or deleted and the information is not printed unless requested by the maintenance personnel. Each of the Work Feedback Cards contain a checklist number, area subsystem numbers and device numbers. These numbers define documents that were generated the last time a change was made on the content of a document.

The previously defined system input requires the checklist number be designated on up to two lists for each piece of equipment in the system. The lists describe in detail the actions to be taken by either the Mechanical or Electrical repairman performing the preventive maintenance work. Lists for each item identified by the area subsystem number and device number are retained by the maintenance supervisor. When the maintenance supervisor receives the work list for each week, he provides the proper checklists for the maintenance personnel. The checklists are retained in the maintenance office on file and are not output from data storage unless updated by the maintenance department. The flexibility of this system is readily apparent. Each week the computer system generates an updated report that eliminates looking back to determine what is outstanding or incomplete. As the routine maintenance is performed on each piece of equipment in the system, major problems are avoided. Equipment that operates on an erratic scheduling sequence can still be pinpointed as requiring attention through around the clock PM work schedules. If major problems are suspected in the near future on equipment as a result of a routine PM service call, a shutdown can be planned and unnecessary long down time avoided. As experience is gained about each of the items in the system, inspection intervals can be increased or decreased to suit each individual case.

The Maintenance Reference Manual is the most comprehensive document supplied by data processing systems. The manual contains the complete set of data about each device in the system. This document is indexed by area subsystem numbers and contains all the information about each device as described previously in the content of the Item Record. This document is updated by the maintenance department using a correction card recognized by the data processing system.

Many references have been made to the Work Feedback Card without detailing its format and content. The object of this card is to provide a maximum amount of pertinent information, pointers to the detailed data document. Pointers to the checklists and allowance for feedback input codes to update the maintenance system. The content of the card is designed to be contained within eighty columns, thus, making it compatible to any computer system. The card is generated by the computer at the beginning of the cycle. After the work is performed the proper codes are marked on the cards and they are returned daily to the computer center. When the card is received at the computer center the written code is properly punched on the card. The cards are then retained until the update sequence is executed and the next week's cards and reports are generated. The new cards and reports repeat the cycle.

Once a card is generated, a new card is not generated automatically until the old one is returned, coded or destroyed. The computer system continues to add production hours to all the equipment even after a card has been issued for inspection servicing. When that card is returned only the hours indicated on the card when it was issued are subtracted from the accumulated production hours. Thus, the system retains the hours put on any piece of equipment even in the interval between the time a Work Feedback Card is issued for service and the time the card is read back into the system.

Since the work schedule runs from Sunday to Saturday, and the new week's schedule is generated on the previous Thursday, it is obvious that some of the feedback cards for the jobs scheduled on Thursday, Friday and Saturday of the previous week will be listed on the Exception Report No. 1. This will serve as not only a check of the systems accuracy but also a reminder for completion to the maintenance supervisor. However, as previously explained, no hours are lost since the update procedure subtracts only the accumulated hours indicated on the Work Feedback Card. There is however a slight overlap of hours between the time the Work Feedback Card is issued and when the work is completed. This means for example, Device A for which a Work Feedback Card was issued in week one with 2,000 hours accumulated time may operate a maximum of 232 additional hours before the required work is performed. The net results is that when the update is made 232 of accumulated hours toward the next inspection is invalid since as presently defined the computer system does not retain the daily applied hours so that when the system is updated the hours up to the completion date are deducted from the accumulated hours. The system could be built to include this daily accounting feature after the Work Feedback Card is issued but, the extra work may not be justified. A study can be made after installation to determine if the frequency of occurrence mandates redesigning this part of the system.

The previous example was the worse case where Device A ran twenty-four hours a day for nine days and sixteen hours on the 10th day. Whereupon the scheduled down time occurred and Device A was serviced. It is probable this condition will eventually occur, but the extra complications in the data processing system may not be justified. This is true since 240 hours only represents ten days of continuous operation. In industry, once a piece of equipment is debugged it should operate well over ten days without service.

The Work Feedback Card has been discussed quite extensively in this chapter, and it is appropriate that the card itself be examined in detail. The Work Feedback Card is shown in Figure 9. The fields on this card are as follows:

1. Area number.
2. Device number.
3. Service code - electrical, mechanical, hydraulic lubrication.
4. Date issued.
5. Number of hours since last inspection.
6. Date and shift to be assigned (unit scheduled down).
7. Date and turn complete.
8. Job completion time.
9. Checklist number.
10. Item Repair Code No. 1.
11. Item Repair Code No. 2.
12. Item Repair Code No. 3.
13. Item Repair Code No. 4.

Most of the items in this list were previously described in the Item Record list. Only the service code and repair code remain undefined. The Service Code is used because a given piece of equipment with electrical, mechanical, hydraulic and lubrication components may

WORK FEEDBACK CARD

1-3	4-7	8-10	11-16	17-20	21-27	28-34	35-38	39-42	43-46	47-50	41-54	55-58	59 - 80
AREA NUMBER	DEVICE NUMBER	SERVICE CODE	DATE ISSUED	NO. OF HRS. SINCE LAST INSP.	DATE AND SHIFT WORK SCHED. TO BE DONE	DATE AND SHIFT WORK COMP-LETED	NO. OF MINUTES FOR WORK TO BE COMP-LETED	CHECK LIST NO.	REPAIR CODE NO. 1	REPAIR CODE NO. 2	REPAIR CODE NO. 3	REPAIR CODE NO. 4	FUTURE USE

80 Column Computer Input Card

FIGURE 9

Work Feedback Card Format

carry the same Device Number. When the Work Feedback Card is generated a service code must be applied so that the proper category of work is performed.

The Repair Code encompasses a list of normal repair problems that may be encountered and overcome. Space is provided for up to four Repair Codes. If less than four describes the work performed, the remaining spaces contain blanks.

There are three other computer system interactions required to fulfill the needs of the maintenance supervisor. These are the New Item Entry, Item Deletion or Change and Document Request. In practice, the supervisor fills out a coding sheet with all the fields properly defined on the sheet. The coding sheet is sent to data processing to be keypunched and used to update the system. These three additional inputs are seldom used after the system is in operation, and most of the interaction will occur with the Work Feedback Card as the input medium. The document request causes the computer to print out all the stored information on the requested device.

The original premise for the maintenance system was to design an effective and desirable tool for the maintenance supervisor. To that end, the system presented here gives the maintenance supervisor the following advantages:

1. A complete informational document on all pieces of equipment.
2. A weekly job assignment planning guide.

3. An effective preventive maintenance system that requires a minimum of paper work.
4. A better manpower utilization guide on a week to week basis.

A system for improving the maintenance of equipment has been described up to this point. Substantial savings should occur, simply from scheduling and control. It is important to note that a by-product of this will be an automatic maintenance labor productivity control systems appraisal. This by-product provides the solution to the remaining problem of maintenance personnel productivity.

When a production worker is assigned to some product line, his output can easily be measured by the units of output achieved in hours worked. Even if the total output is attributed to a group of workers, the individual participation of each worker can be defined. On the other hand, the support groups of maintenance personnel are not so easily measured. Various systems of incentive payments have been developed for maintenance personnel. The systems investigated do not monitor the daily activity of each man and relate that activity to any planned work and unexpected service calls. The system described in this thesis simply makes use of data already produced by the product line, collected by the process control computer and transmitted to the host data processing computer. From this, maintenance personnel productivity can be measured.

As previously described in this chapter, the product line delays are automatically recorded by the process control computer. The delays are then transmitted to the data processing computer for summarizing and report generation. This delay data is also applied to incentive rate calculation for the production workers. The delay data along with production output is insufficient for measurement data on maintenance personnel. There must be some way to determine if the assigned work was completed on each shift, and if not, were the delays experienced on a given shift of sufficient magnitude to offset the incompleted assigned work.

The assigned work is generated through the preventive maintenance system. Over a period of time the work assignments of the preventive maintenance system can be time studied and the total time for completion assigned to each job. The maintenance supervisor can then determine the shift assignments using the weekly equipment maintenance list and the two weekly exception reports. The standard time for job completion of each job is listed for each Work Feedback Card issued. This feature is provided so that the maintenance supervisor can distribute the work load adequately across all shifts. Space is provided on the Work Feedback Card to enter the actual job completing time.

It may be that there are not enough preventive maintenance jobs available to fill a given shift. In this case the maintenance supervisor must use the Additional Work Assignment card. (NOTE: this is only the second piece of paper required for the entire feedback system.) This card contains shift, date, Device Number, Service Code, Repair Code, Area Number, Estimated Time for Completion and Maintenance Supervisor Code No. It is returned with the Work Feedback Cards for that shift. It acts as a catch all tool for the undefined jobs that always seem to occur. Its format is shown in Figure 10.

The host computer now has the complete set of data required to determine the output of the maintenance personnel for each shift in a given week. As stated earlier, the Work Feedback Cards and now the Additional Work Assignment Card are only run once a week. The Additional Work Assignment file is updated for use with the productivity calculating and reporting procedures. It has no other function.

With the shift delay, productive output, Work Feedback Cards and Additional Work Assignment Cards, all the data necessary for productivity calculation are available. By defining "Perfect Productivity" to be Unity(1) Work Completed divided by Work Assigned is the Productivity Achievement Rating. Work Completed is the sum of the Work Feedback Cards completed plus Additional Work Assignments completed plus Service Calls completed as a result of production delays. Work Assigned to the sum of the Work Feedback Cards assigned and Additional Work Assignment Cards. The data requirements for the computer are now completed. The data processing computer can now report the daily shift productivity for the previous week. This is

ADDITIONAL WORK ASSIGNMENT CARD

1-3	4-7	8-10	11-16	17-20	21-27	28-34	35-38	39-42	43-46	47-50	51-54	55-58	59 - 80
AREA NUMBER	DEVICE NUMBER	SERVICE CODE	SUPERVISOR CODE NO.	FORMAT IDENTIFIER	BLANK	DATE AND SHIFT WORK SCHED. TO BE COMP-LETED	NO. OF MINUTES FOR WORK TO BE COMP-LETED	BLANK	REPAIR CODE NO. 1	REPAIR CODE NO. 2	REPAIR CODE NO. 3	REPAIR CODE NO. 4	FUTURE USE

80 Column Computer Input Card

FIGURE 10

Additional Work Assignment Card Format

achieved by examining the Work Feedback Card Assignment and Completion dates and turns. The delays for each shift with time started and time completed and the Additional Work Assignment Card with dates and turns for issuance and completion, form the data for the productivity achievement calculation. These data values are then plugged into the formula, resulting in some number from 0 to 1.0 as the "Productivity Achievement Rating". Productivity ratings greater than 1.0 show performance better than projected by the maintenance supervisor. The final report gives the supervisor by date and turn the "Productivity Achievement Rating" plus a listing of the Work Assigned and the Work Achieved. The maintenance supervisor can now analyze what groups of employees work best together, which delay problems are most frequent, which men best perform certain jobs, which men minimize delay time, and many other useful points.

The complete utilization of the power of such a system as this can only be realized when the data processing computer is put to further use correlating these data with the other available data. This system also has possibilities in the area of rate calculation. To achieve this the system would have to be expanded and refined. It is presently only designed to be a reporting tool for the maintenance supervisor.

This chapter describes a scheme for a completely integrated Preventive Maintenance System and a maintenance measurement system.

Now a method must be found to investigate and compare the performance between the more conventional Calendar Bases System and the Usage Based System. Inasmuch as setting up this scheme in the real world requires very specialized and expensive equipment, a simulation must be made to compare whether the new system works better than the previous or currently used systems. As a matter of fact two simulations are required. A simulation must be developed for the Calendar Based and the Usage Based System and the results compared.

Chapter IV deals with the experimental procedures associated with the actual simulation and its development. At this point, however, an evaluation of the progress toward solution of the proposed problems is justified. This chapter has developed two schemes which solve the stated problems at the beginning of this thesis. The Preventive Maintenance System described reacts on a weekly basis to all equipment which has equalled or exceeded the production hours of operation determined as an acceptable interval of preventive maintenance. Reports and documents are generated that supplement any needs of the maintenance supervisor. Also shown here is that the data contained in the overall system with minimal supplemental data manipulation and information can provide output reports describing the work productivity on a shift by shift basis for the maintenance personnel.

CHAPTER IV

SYSTEM SIMULATION MODEL

To investigate adequately the ability of any preventive maintenance system to react according to the parameters outlined in the chart in Chapter II and the system described in Chapter III, a simulation model must be designed and operated. Such a model incorporating every detail of the proposed system presents an enormously difficult task. However, this thesis investigation described some basic parameters for a preventive maintenance system. These parameters encompass the truly necessary simulation model objectives. As a future area of investigation, the intricacies of the detailed system could be modeled. Completion of this thesis investigation requires a simulation model that adequately compares the two maintenance philosophies of Calendar Based control and Usage Based control. The data generated by the simulation also must provide a basis for evaluation of manpower productivity objectives.

For the model it must be assumed that the data collection system using process control computers does function. For the simulation model both the data collection system and the data processing system perform their respective duties required either internal or external to the model. The model deals with a system of operating components called Device (X) where X is 1 to N (N has a maximum of 200) and the manpower servicing Device (X) for PM and breakdowns. Where equipment operations are scheduled requiring the operations of groups of devices, all operating sequences are group oriented. This is similar to equipment in an area subsystem described in Chapter III operating as a unit, and failing as a unit.

The events that describe Device (X) include Start of Operation, End of Operation, Start of Breakdown, End of Breakdown, Start of Preventive Maintenance and End of Preventive Maintenance. Using the simulation technique of event control, the model is developed around Gasp II simulation language.

The output requirements of the model must be Device (X) oriented and system oriented. The output data must be able to substantiate the possible advantage of one PM system over another. In the model PM system, Type I is the system using arbitrary time intervals between PM service calls (Calendar Based) and PM system Type II uses the actual operating hours (Usage Based) as a trigger for PM calls.

Output must also consider manpower productivity between the two PM systems and also during operating and breakdown periods. The output data expected from the model includes:

1. For Device (X)
    a. Total breakdown time.
    b. Number of breakdowns.
    c. Number of breakdowns avoided because of PM.
    d. Number of PM calls.

e. Total operating hours.

f. Number of delays.

g. Total delay time.

2. For System

a. Number of times of no PM man available

b. Number of times PM man used for breakdown.

c. Waiting time for repair calls.

d. Statistics on holding queue for repair calls.

e. Summary statistics on Device Variables.

The model is initialized with the type of maintenance system to be tested, whether the devices are group operated or individually operated. The number of repair servicemen available and the number of PM men available are also part of the set-up data.

Using a psuedo event for initialization, the event file is filled with a single starting event for each device in the system. The model then continues on its own, scheduling events as the conditions are met.

The model is designed to handle up to 200 devices individually or group operated. The groups can be any size evenly divided into 200. Each starting event for a given device triggers an ending event for that device. The Start Operation event schedules an End Operation event, and the End Operation event schedules the next Start Operation event for Device (X). This also occurs for the Start PM event and the End PM event and the Start Breakdown event and End Breakdown event.

The events themselves have an operating priority. The objective is to have any device ready to operate when a Start Operation event occurs so that no delay occurs. If for example, a Start PM event had begun on Device (X), the End PM event must occur before operation of Device (X) may begin. In this case the End PM event is triggered as soon as there is a requirement to use Device (X) for operation. This is probably the simplest situation to handle.

When a Start Breakdown event occurs, the device must be repaired before the Start Operation event can occur. Thus the End Breakdown event must occur and the delay time recorded. If a Start Breakdown event occurs and the device was previously started into operation, the operation must be suspended and a delay recorded until an End Breakdown event occurs. After this event the Start Operation event is resumed. The only event not suspendable is the Start Breakdown event.

Since there is no data available and every plant probably experiences a different set of actual scheduling and delay frequencies, the model uses uniform distributions to calculate and trigger times between events. The model is designed with a plug-in feature to change the distributions to any set of data relative to an actual shop performance record. For this reason, the data generated have no direct correlation to an actual shop. However, for the purposes of the comparison of this thesis investigation, as long as the two types of maintenance systems use the same distributions the data and information derived from the data can be used for conclusive evaluation.

The model although built to include group operation is not completely tested in this mode. Time constraints prohibited final debugging of the group operation mode. Therefore, this will be left for future completion. There are more than enough data for comparison employing the individual operation mode for the Type I - Calendar Based PM system and the Type II - Usage Based PM system.

Certain utility routines are used to support the model. "Fileck" is used to search the event file on a periodic basis to be sure there is a breakdown in the event file for each device. This function is required since under both modes of operation, breakdowns are avoided fifty percent of the time if PM is carried out. This percentage may be higher or lower in reality and can be modified easily. However, since the model is event triggered, no breakdowns would ever occur after an avoided breakdown was removed from the event file. In fact, no matter how well any maintenance program works, breakdowns will occur. "Fileck" does the search and when no event is found for a device a Start Breakdown event is scheduled at some event time well beyond the normal interval of breakdowns.

The "Initz" Subroutine is used to initialize the event file and other arrays that are used as reference data in the model. This event only runs once at the very beginning of the program.

There are also some basic philosophical differences in the operation of the two maintenance modes. These are in the usage of manpower. In the Type I system, PM men are only available on the day shift and in Type II, PM men are available on all shifts. Therefore, to insure equal numbers of PM men in both systems, Type I is initialized with three men and Type II is initialized with one man. This works out to a total of 21 man shifts per week in each mode. In the Type I system, PM events are scheduled for day shift only. The Type II system schedules PM events around the clock.

Productivity performance in the model is not as detailed and intricate as the system described in Chapter IV. This is simply because modeling such details exceeds constraints limiting the writer to the time frame of this thesis. Nevertheless, a value can be determined to compare the utilization of the manpower in one system with the other. This is thus a productivity factor of one system over another. This factor for the model is the Total Equipment Delay Hours divided by the Total Scheduled Operating Hours. The difference in the two systems shows the response time of maintenance personnel to failure occurrences.

The model uses the basic premise that PM servicemen are available for breakdown work when regular service people are busy on other repairs. This essentially allows for extra manpower on an around-the-clock basis for Type II operation. In the Type I system there are no PM service people other than day shift.

Productivity can further be compared by evaluating the parameters such as maximum number of repair calls in the queue because all personnel available for repairs are busy. PM productivity factors between the two systems are also apparent by comparing statistics regarding the number of PM calls performed and the number of PM calls scheduled because the device to be serviced was operating at the time the preventive maintenance was scheduled. These are all valid factors since the number of PM manhours worked is constant for both systems.

To collect data for final comparison, eight runs were made for each mode of the model. The variables that were changed from run to run were the number of repair service people and the number of PM service people. The model run time was 10,200 hours in all cases.

The reason for changing the number of service people was to determine at what point the number of manhours put into the system had little or no effect on increasing the up-time of the equipment. This will also show any limits on the PM program with respect to increased performance hours of the equipment.

The sixteen runs for data collection include eight runs of each maintenance system. There are eight manhour configurations used which are run with each system providing eight sets of parallel data to be compared.

Runs One through Eight for system Type I as listed in Figure 11 included four repair servicemen and three PM men, six repair servicemen and three PM men, eight repair servicemen and three PM men, ten repair servicemen and three PM men, four repair servicemen and six PM men, six repair servicemen and six PM men, eight repair servicemen and six PM men, and ten repair servicemen and six PM men, respectively. The corresponding Runs for One through Eight for system Type II as listed in Figure 11 included four repair servicemen and one PM man, six repair servicemen and one PM man, eight repair servicemen and one PM man, ten repair servicemen and one PM man, four repair servicemen and two PM men, six repair servicemen and two PM men, eight repair servicemen and two PM men, and ten repair servicemen and two PM men, respectively. The data collected from these runs provided the basis for concluding the results of this investigation.

Flow charts of the major event subroutines of the simulation model are included in Appendix I.

CHAPTER V

RESULTS AND CONCLUSION

The model was run to simulate 10,200 hours or 425 days using the eight different manpower configurations for each mode of operation. The data clearly indicates there are gains in all areas where scheduling of PM is done on a usage based philosophy (Type II mode). Figure 11 shows the comparison of the data values collected and calculated for the two systems. The key to the column numbers defining the variables compared in Figure II are as follows:

Variable No. 1 - Percent Delay Hours of Scheduled Operating Hours.

Variable No. 2 - Percent Delay Hours of Scheduled Manhours.

Variable No. 3 - Number of Breakdowns Avoided Because of PM.

Variable No. 4 - Number of PM Calls Performed.

Variable No. 5 - Number of PM Calls Rescheduled Because Equipment Was Operating.

Variable No. 6 - Highest Number of Service Calls In Repair Queue.

Variable No. 7 - Average Waiting Hours In Repair Queue.

Variable No. 8 - Total Number of Service Calls in Repair Queue.

Variable Descriptions	Number 1 Percent Delay Hours Of Scheduled Operating Hours		Number 2 Percent Delay Hours Of Scheduled Manhours		Number 3 Number of Breakdowns Avoided Because Of PM		Number 4 Number Of PM Calls Performed		Number 5 Number Of PM Calls Rescheduled		Number 6 Highest Number Of Service Calls In Queue		Number 7 Average Waiting Hours In Repair Queue		Number 8 Total Number of Service Calls In Repair Queue	
System Type	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
Run No. 1	3.57	2.97	22.1	18.2	663	2087	1802	5418	4663	5831	32	39	6.6	17.6	597	187
Run No. 2	3.36	2.95	14.8	12.8	631	2151	1778	5594	4578	5818	32	39	8.6	41.5	154	45
Run No. 3	3.22	2.70	11.0	9.1	679	2128	1793	5611	4664	5794	27	32	22.4	28.2	32	39
Run No. 4	3.25	2.78	8.9	7.8	654	2178	1783	4615	4495	5784	23	27	17.5	21.1	28	36
Run No. 5	3.43	2.90	17.6	15.7	646	2315	1759	5869	4343	5814	33	37	5.6	36.2	592	64
Run No. 6	3.30	2.73	12.6	10.4	640	2302	1797	5842	4373	5777	25	37	7.2	39.4	149	38
Run No. 7	3.09	2.78	9.3	8.5	653	2262	1779	5850	4202	5787	19	31	11.3	24.1	45	36
Run No. 8	3.30	2.79	8.4	7.1	645	2324	1794	5908	4556	5825	8	18	6.2	13.6	25	33

SIMULATION MODEL DATA COMPARISON

FIGURE 11

The most significant difference between the two systems is found in the preventive maintenance aspects of the systems. The number of breakdowns avoided in system Type II were in all cases at least three times greater than system Type I. This is easily explained with the support of Variables Four and Five.

Variable Four depicts the total number of PM calls performed. This value for Type II is almost 2.5 times greater than Type I. There are several reasons that account for this. In the Type I system PM occurs on day shift only and if the device was operating when scheduled for PM, the work could not be performed. The work had to be rescheduled until the unit was operating and it was also day shift. Since the Type II system has PM men in all shifts, the PM work is scheduled for as soon as the device ended operation. Thus the chance of missing a PM check was diminished.

Variable Five shows the number of PM calls that had to be rescheduled because the device was operating at the time the PM was due. The most significant factor about this variable is for system Type I, where the total number of PM calls rescheduled is significantly larger than the actual number of PM calls performed. This means that some devices were rescheduled so often that they overlapped to the next PM cycle before they were serviced. The Type II system shows that although many devices had PM rescheduled, they always were serviced soon after the End Operation event occurred. The next Start PM event could not occur until the accumulation of operating hours triggered the event.

Variables Six, Seven and Eight deal with the repair queue. The only outstanding fact evidenced here shows the total number in the queue over the entire run was significantly less in the Type II system when the number of servicemen was less than eight. The reason for this is that the PM man was available on all shifts to assist the servicemen on repair work if the need arose. This essentially provided additional help when needed to keep the queue low.

Variable One indicates there were more productive operating hours available because the failures were handled faster. This is reflected as the percentage of delay hours of scheduled operating hours. This number is derived by dividing the Total Operating Hours by the summation of Total Operating Hours and Delay Hours in the eight comparison runs of the model. The differences ranged from .31 to .6 percent gain in productive hours. These gains are derived from the hypothetical scheduling data used in this model. The actual gains may be greater if actual plant equipment failure and scheduling data could be used in the model. The fact that identical scheduling input data used in the comparison runs produced gains indicates some degree of success.

Variable two expresses these gains in production time as a percentage of the Delay Hours of Maintenance Manhours expended. In all cases the Type II runs showed better percentages. The combined information gained from Variables One and Two indicates that as a direct result of the utilization of manpower in the Type II system production gains are achieved. This supports a basic premise of this investigation. The Type II system of PM by actual operating hours and around the clock scheduling of PM personnel can provide better PM performance and also help reduce delays resulting from equipment failures.

The around the clock scheduling of PM personnel also provides additional emergency support for other servicemen when conditions occur that require additional repair support. This minor reallocation of manpower from the Type I system results in production gains for the entire plant or shop. This should result in profitability gains for the plant or shop.

CHAPTER VI

SUGGESTIONS FOR FURTHER INVESTIGATION

It seems clear that there is merit in Type II operation of Preventive Maintenance Systems. However, the problem will be to get a real test situation started. Only actual data can truly substantiate what has been discovered statistically. It may be that some additional work should be done on the model to investigate some of the other areas to determine their effects on the overall system. These areas include not only the completion group operation philosophy, but also the cost accounting aspects of the model. Both of these areas could provide valuable information for study.

The model as it is presently configured included as comprehensive a set of parameters governing maintenance activities as is typically experienced. The ground work prepared in this model provides an excellent spring board for the future study of the areas mentioned.

The task at hand is to work toward introduction of this system into an operating shop. Typically such an extreme change from the norm will not be easy but well worth the effort.

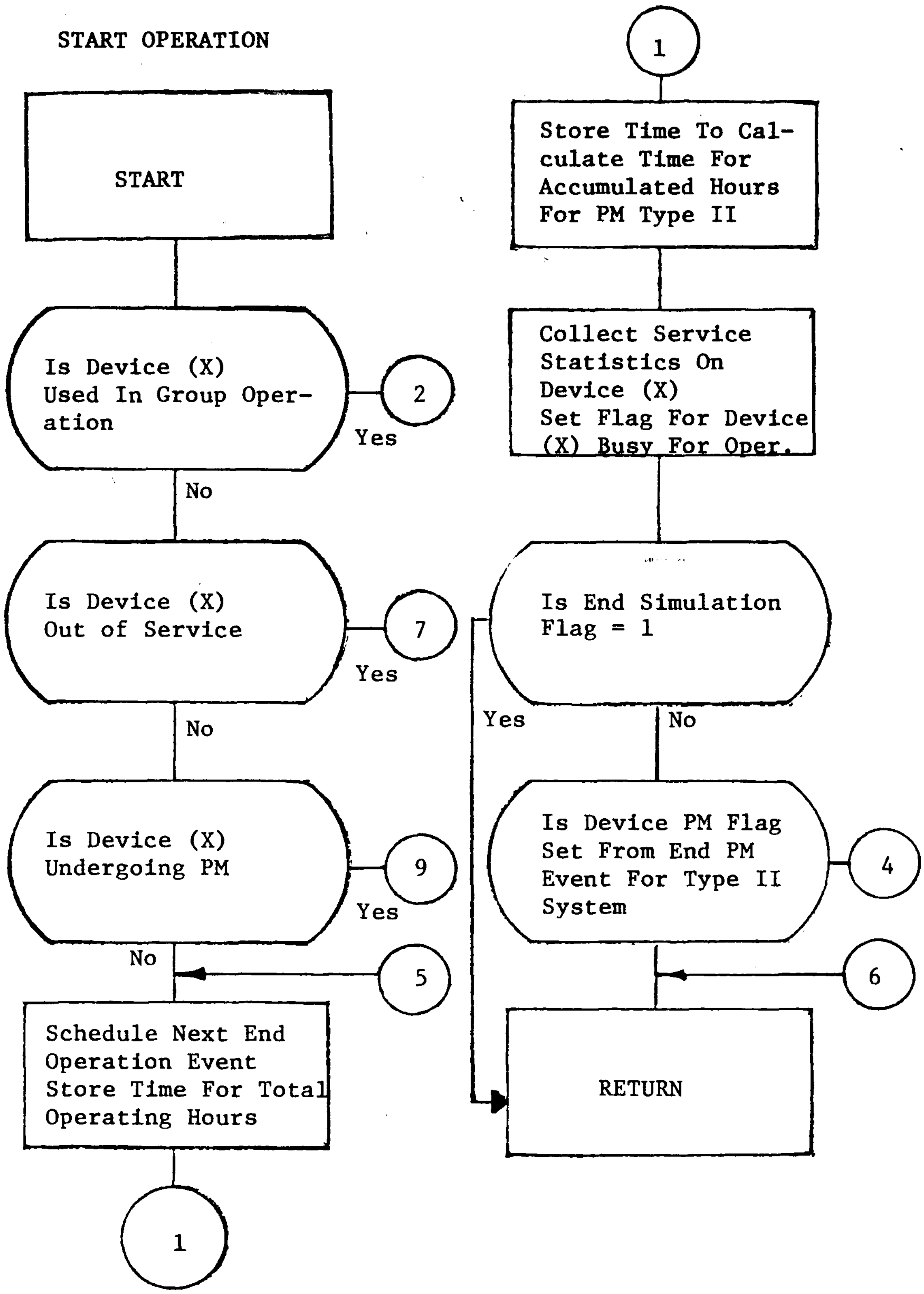
APPENDIX I

SIMULATION MODEL

MAJOR SUBROUTINE FLOWCHARTS

SUBROUTINE

START OPERATION



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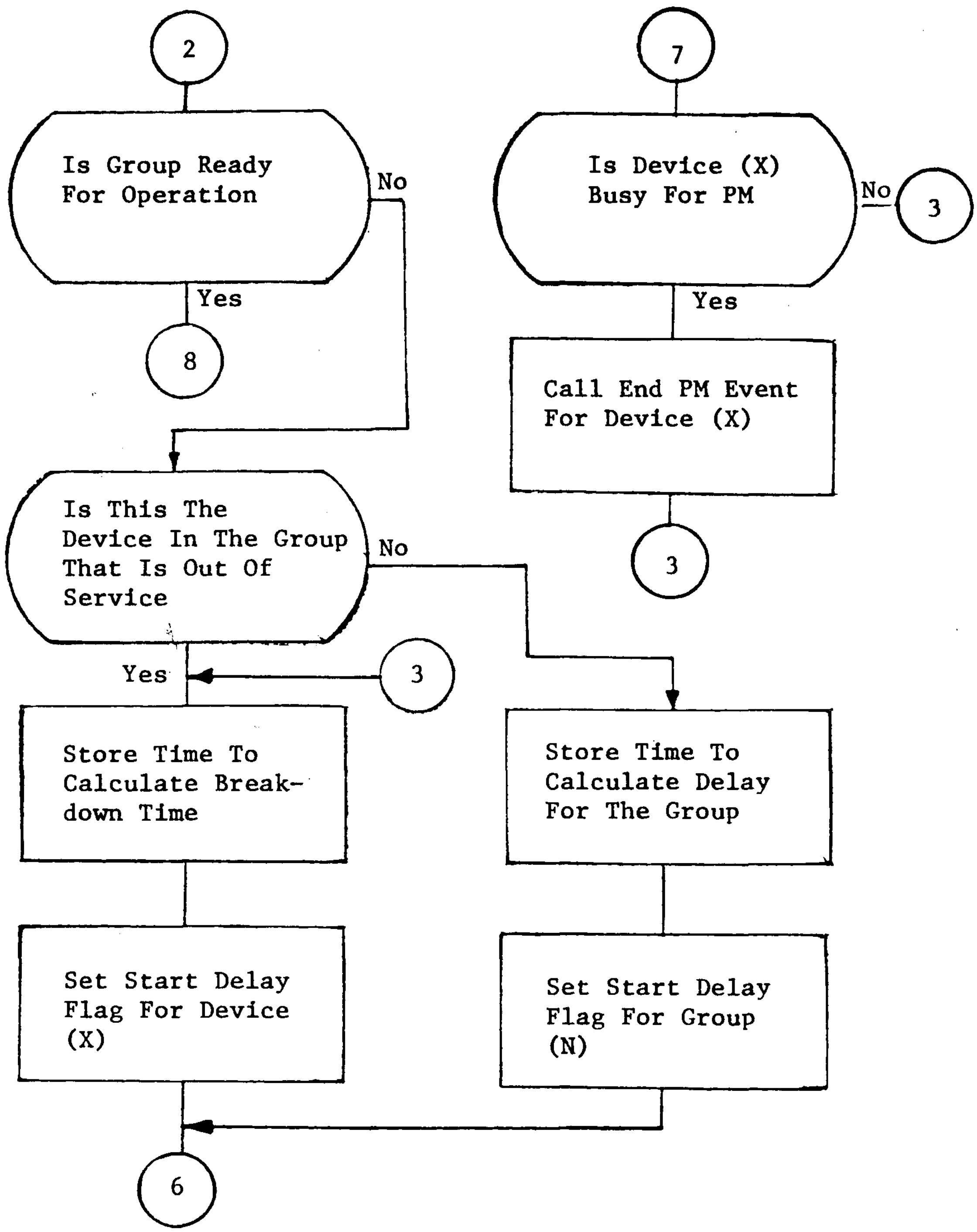
START OPERATION



SUBROUTINE

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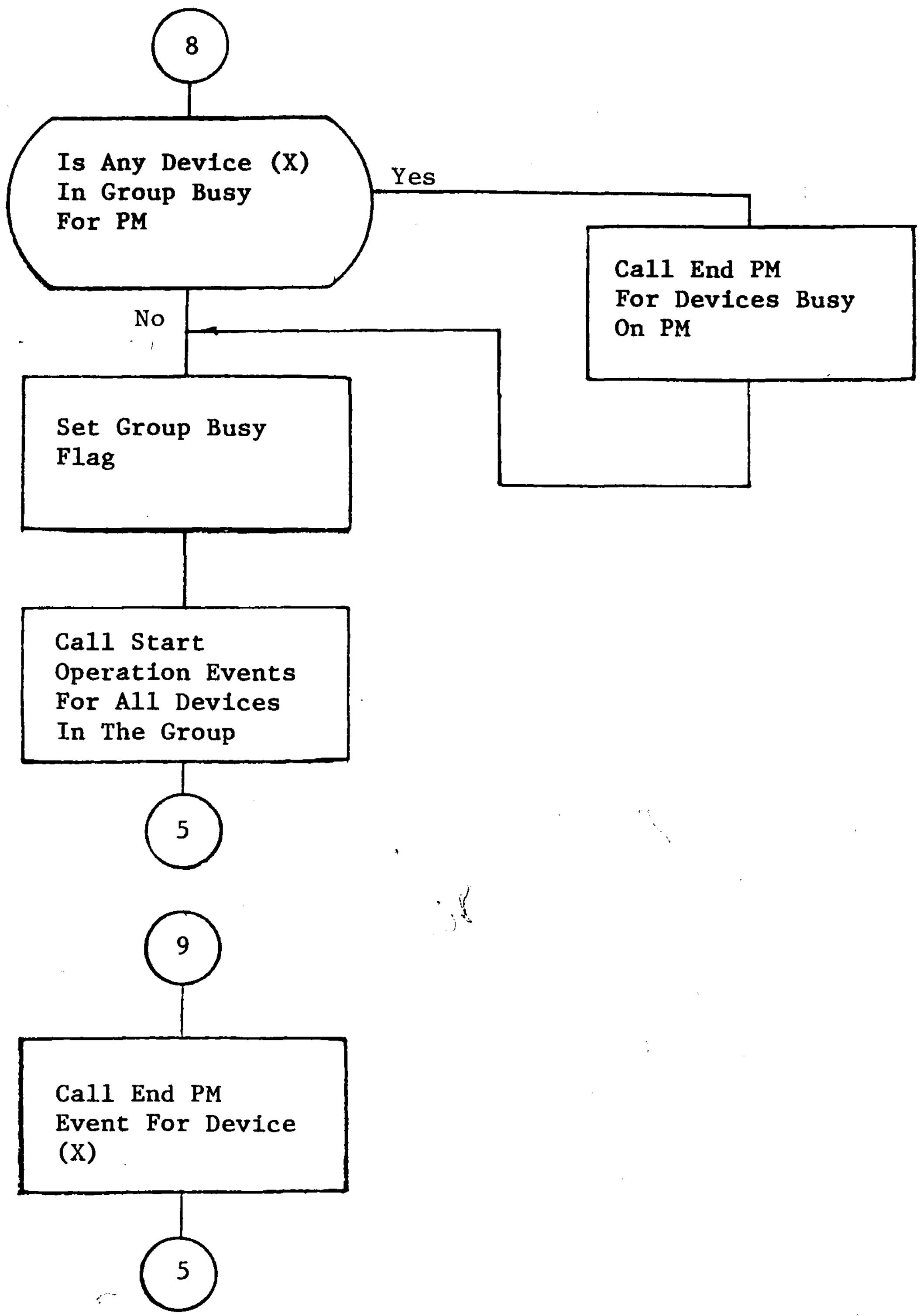
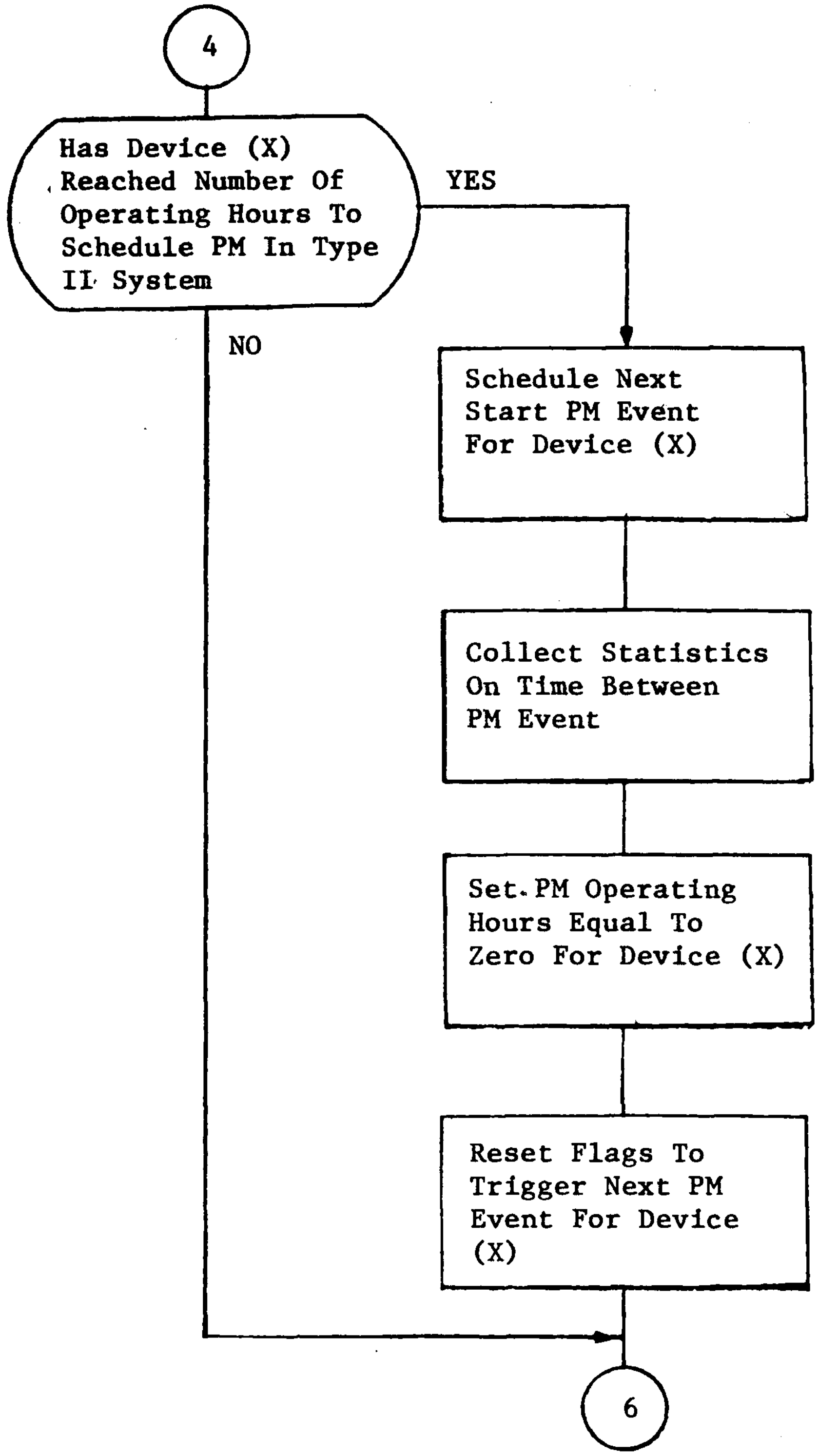


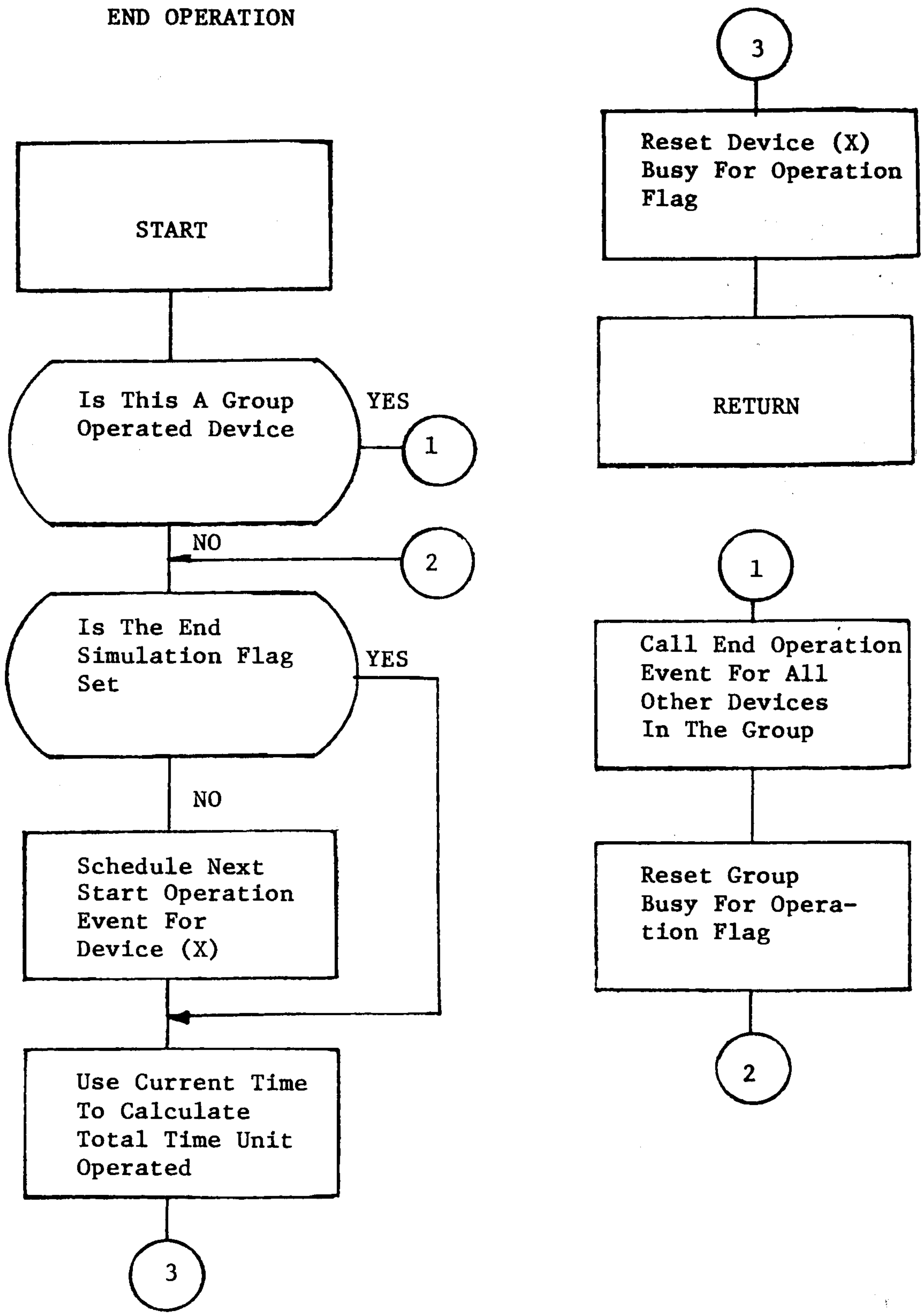
SUBROUTINE

START OPERATION



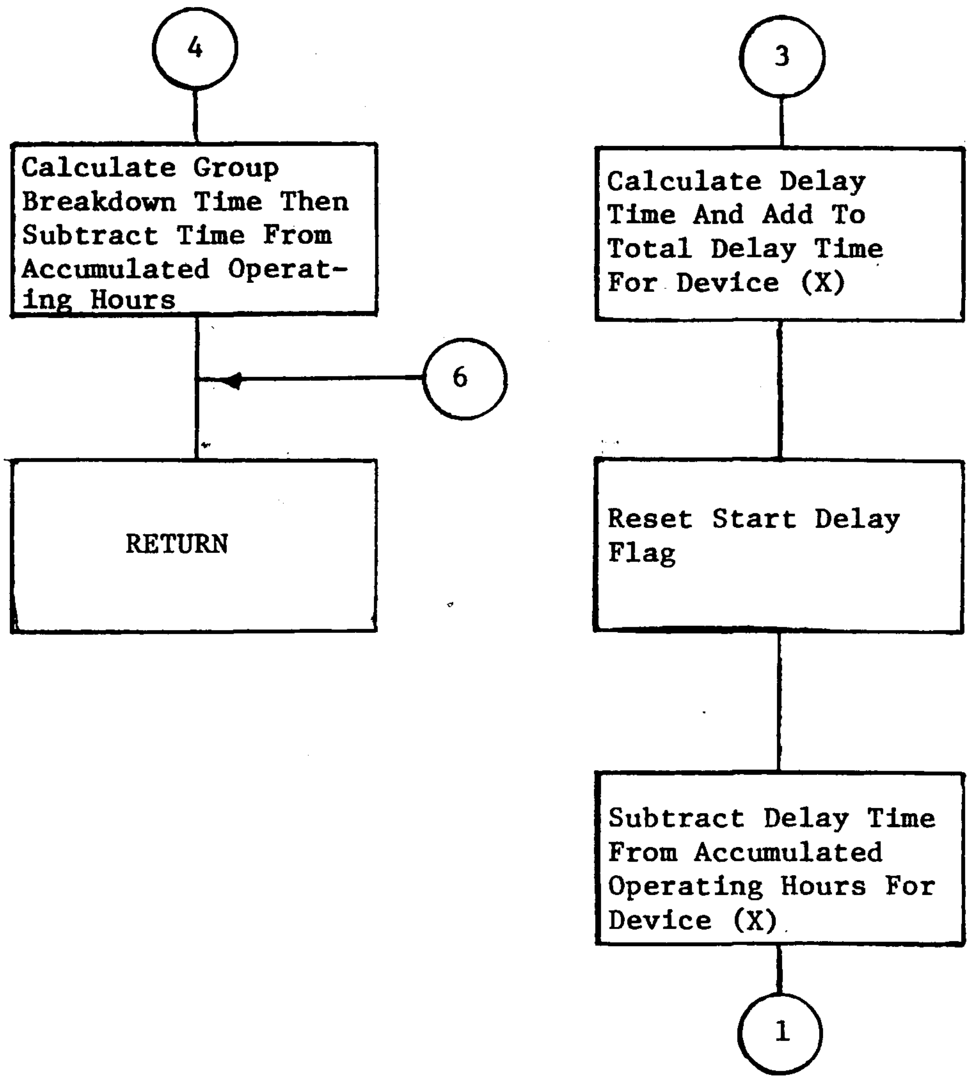
SUBROUTINE

END OPERATION



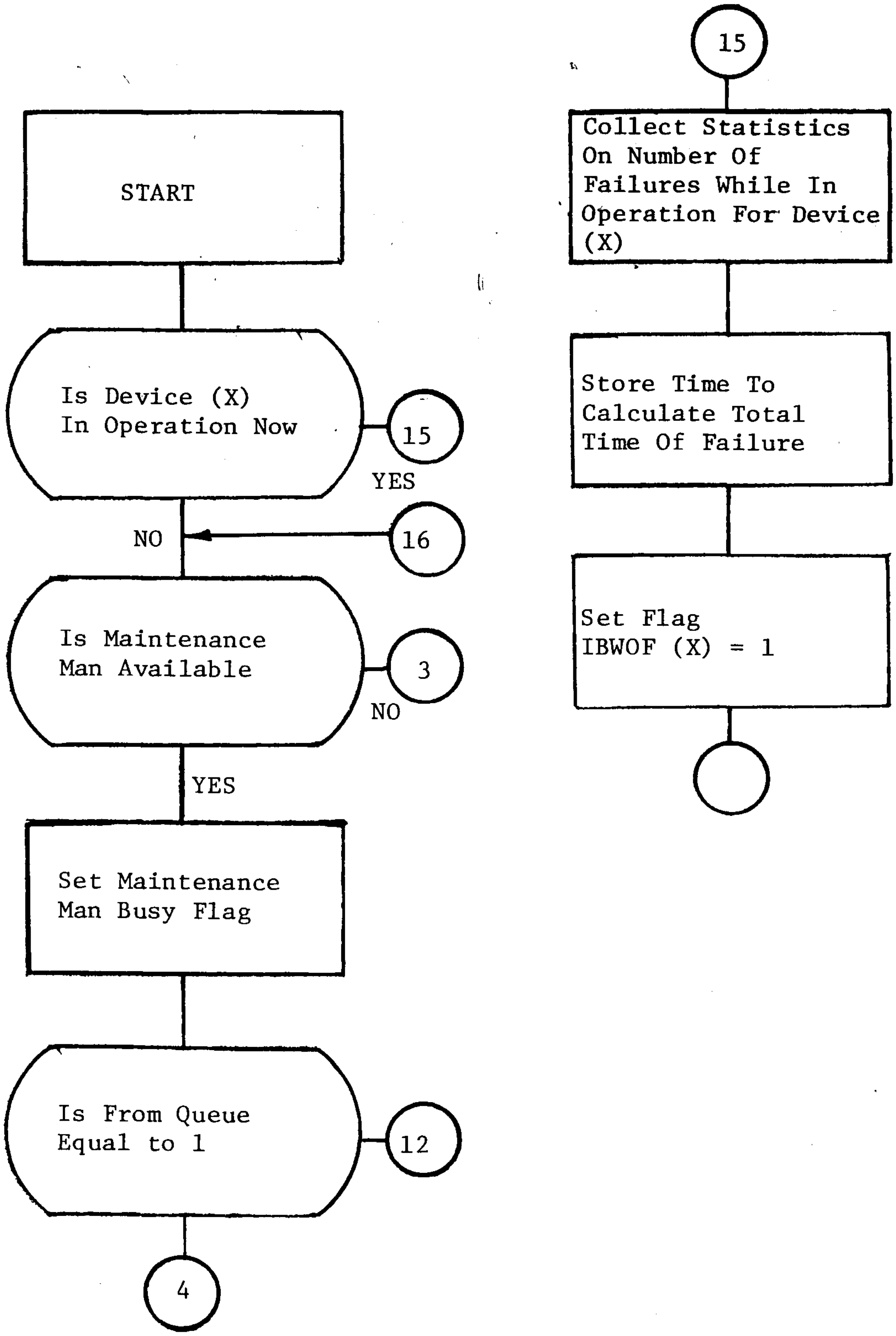
SUBROUTINE

END OPERATION



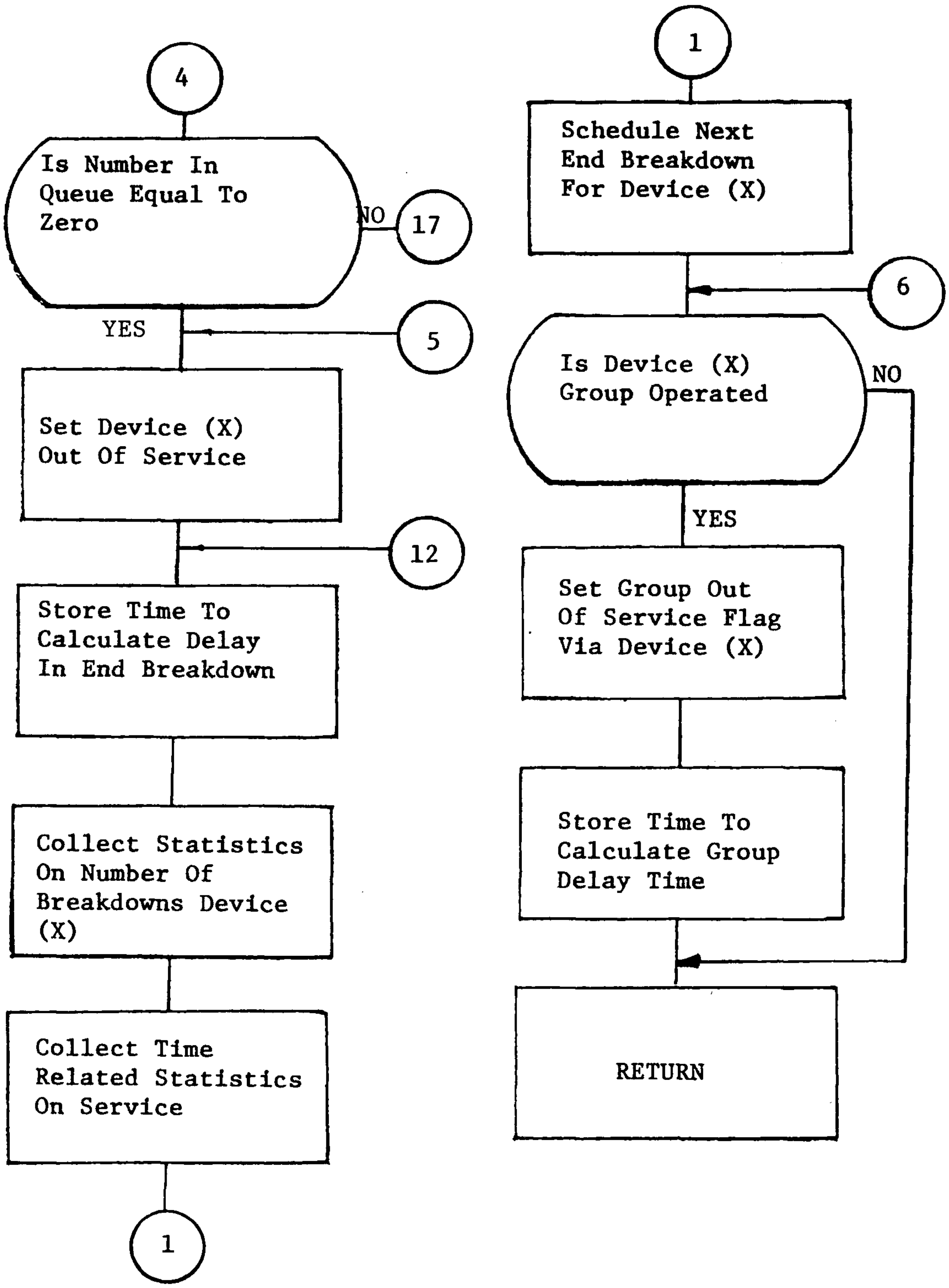
SUBROUTINE

START BREAKDOWN



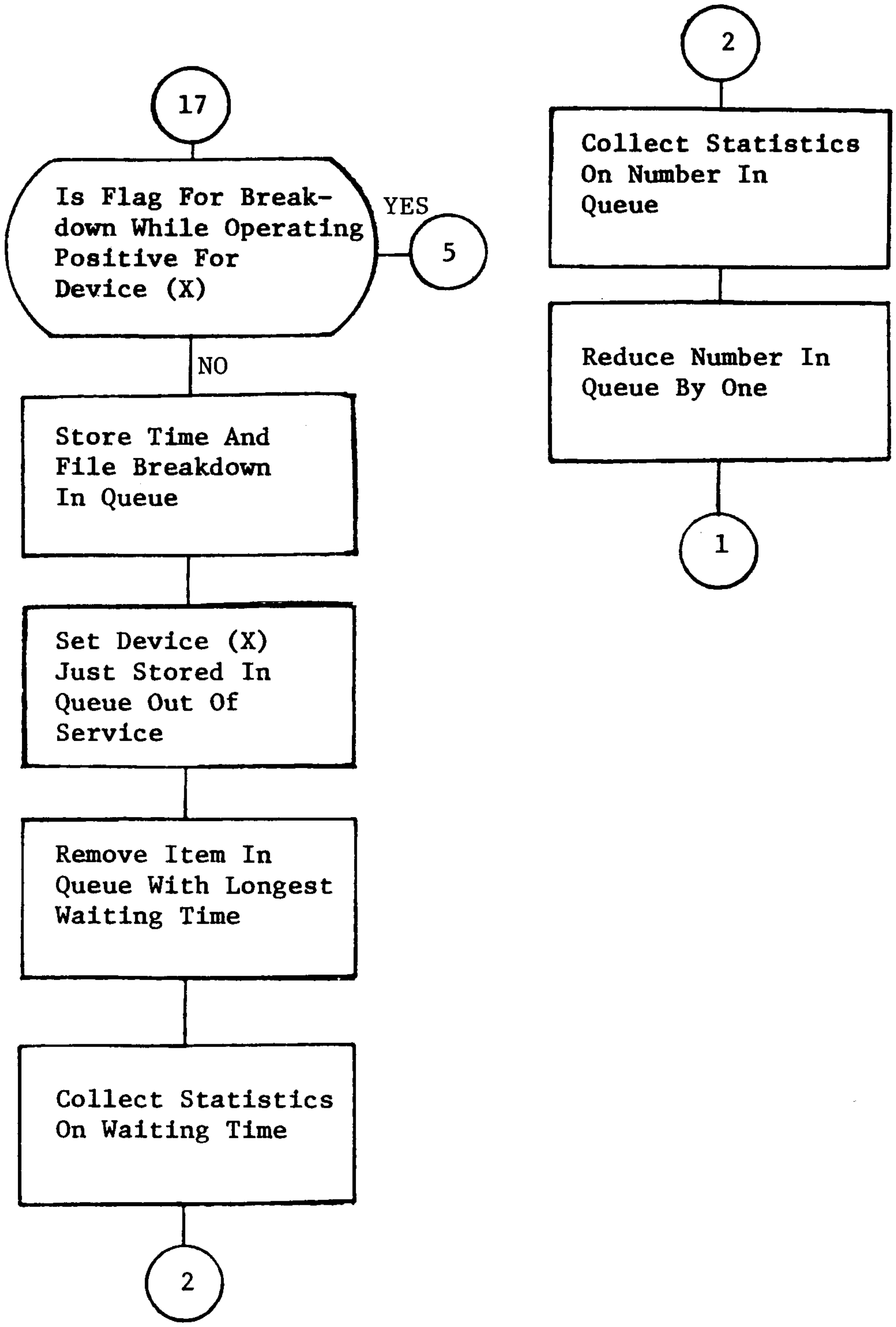
SUBROUTINE

START BREAKDOWN



SUBROUTINE

START BREAKDOWN



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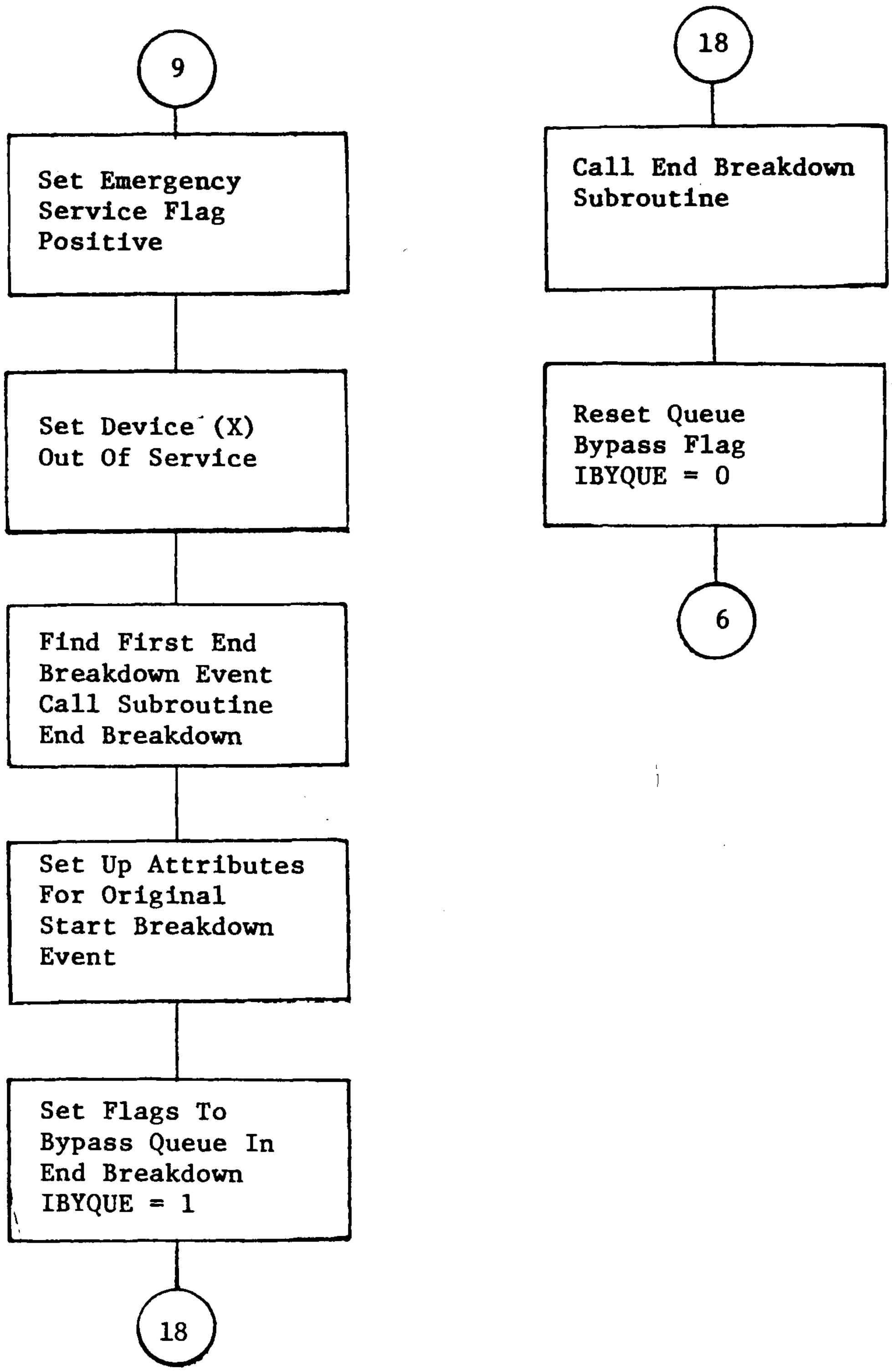
START BREAKDOWN



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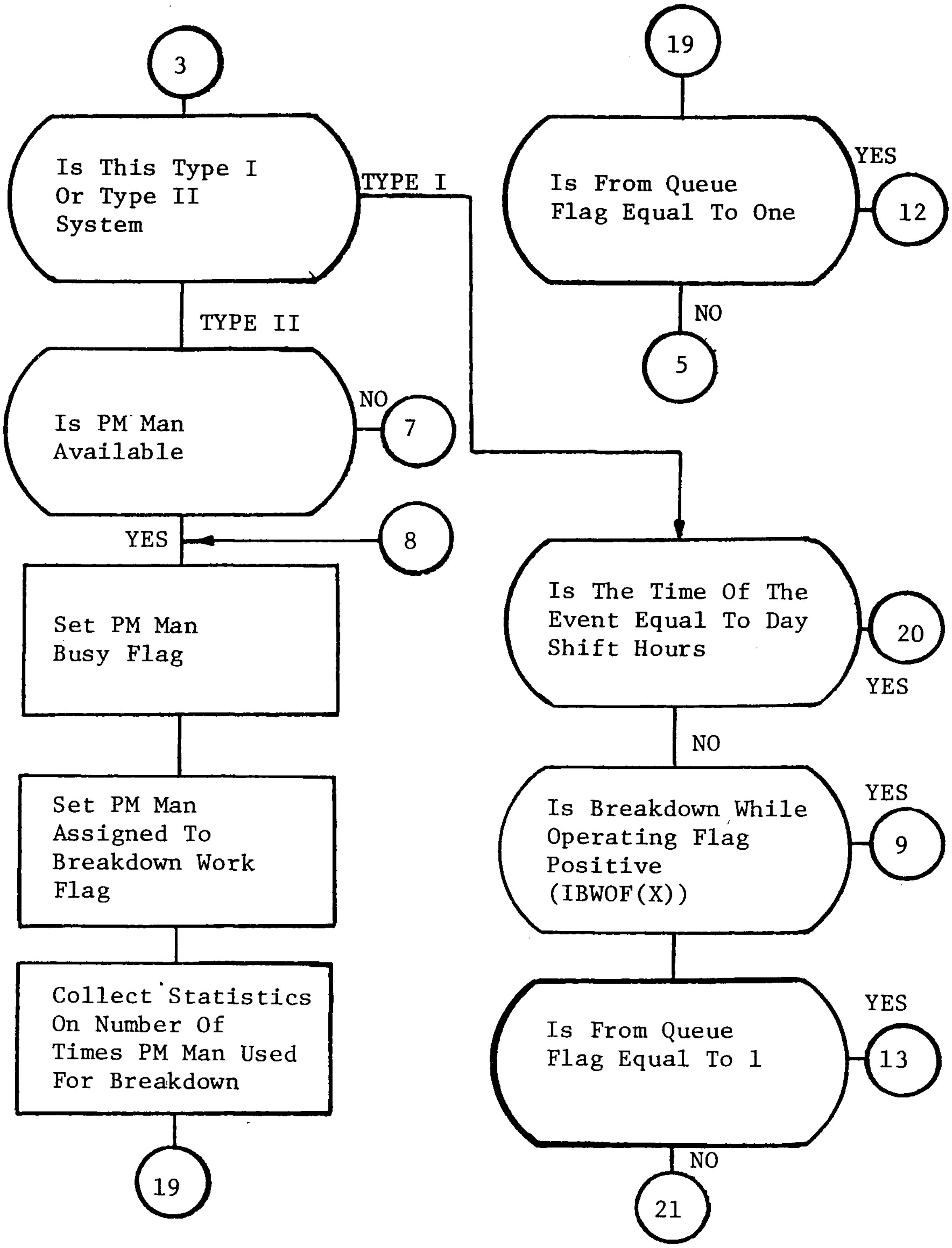

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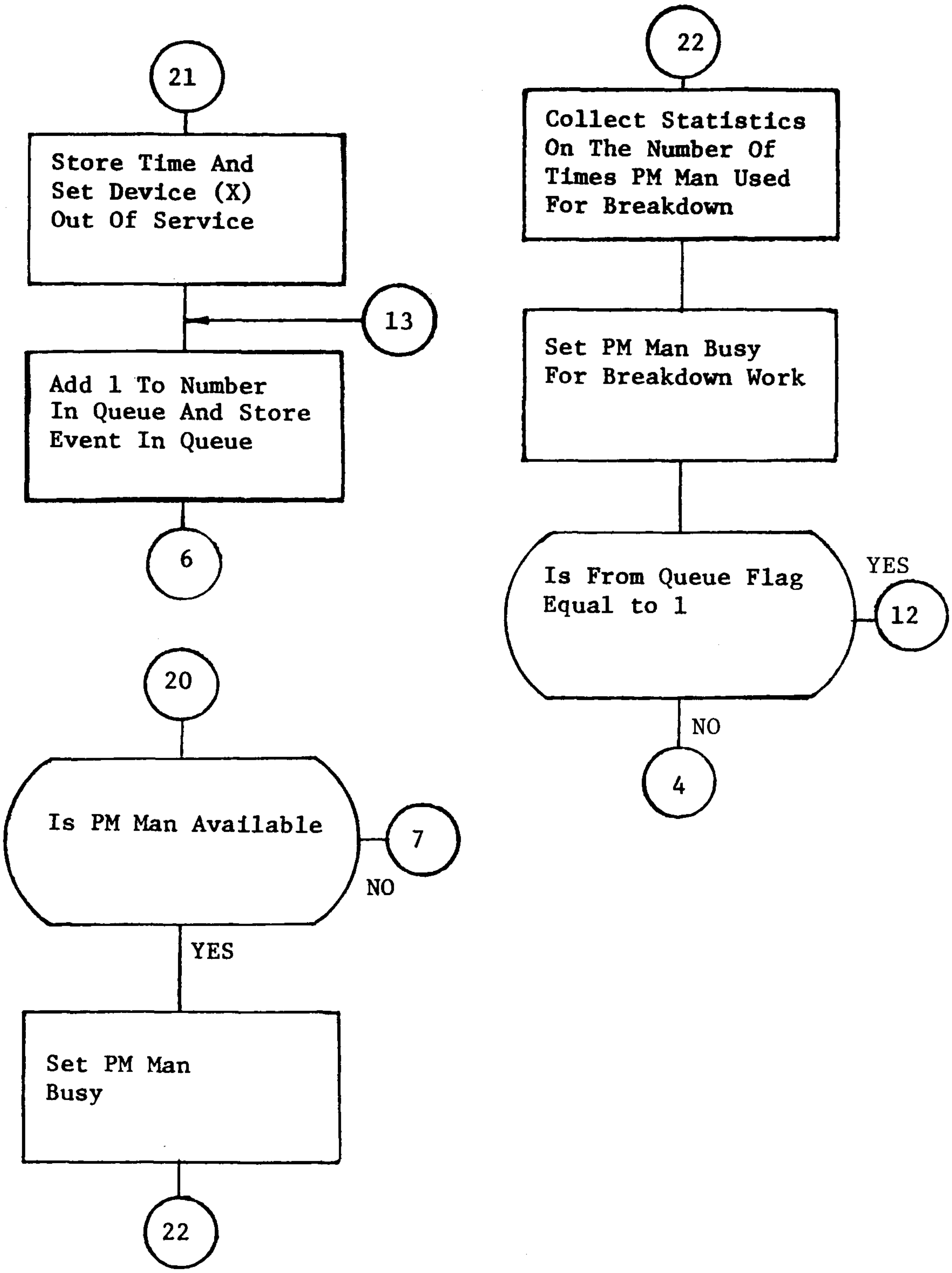

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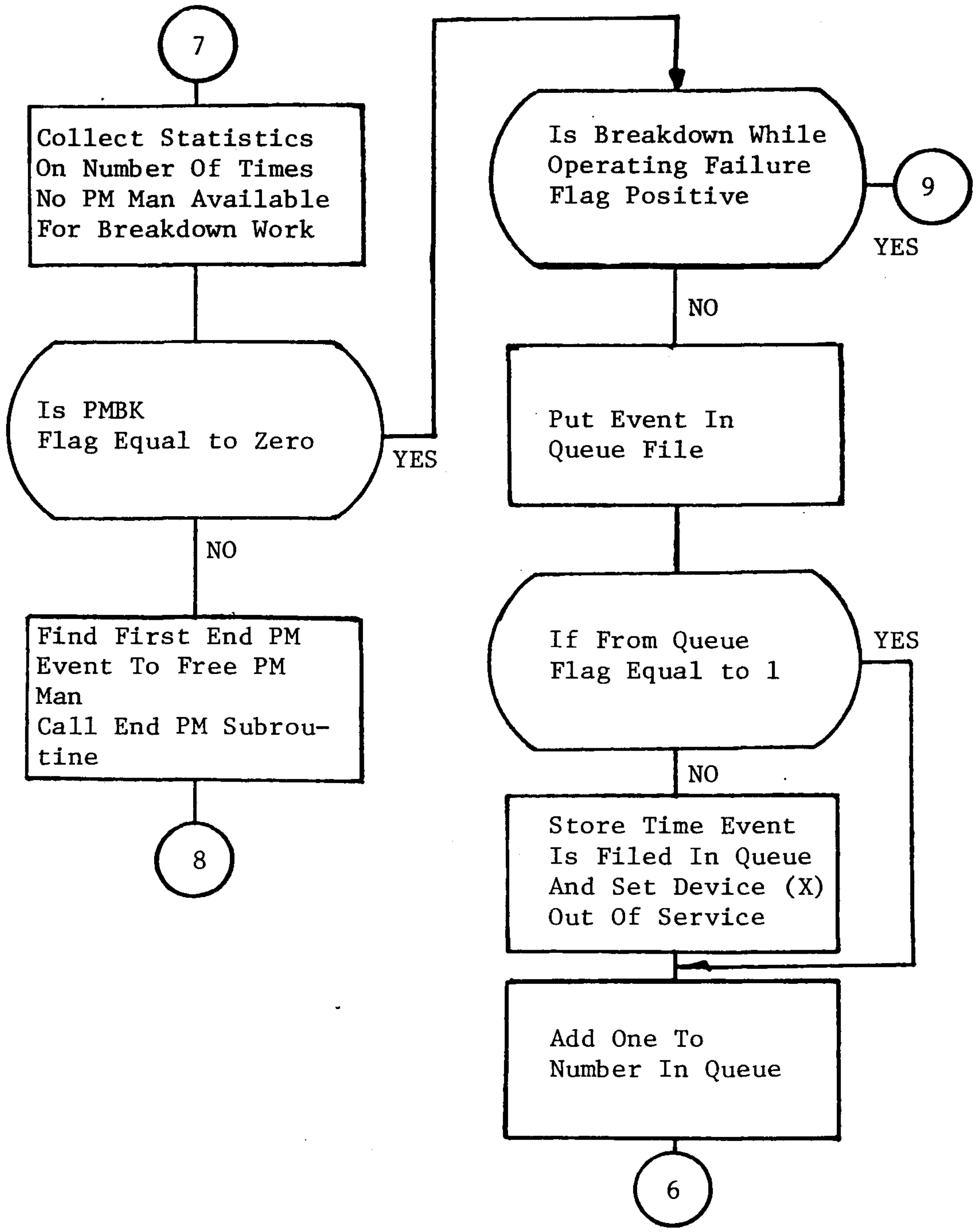
START BREAKDOWN



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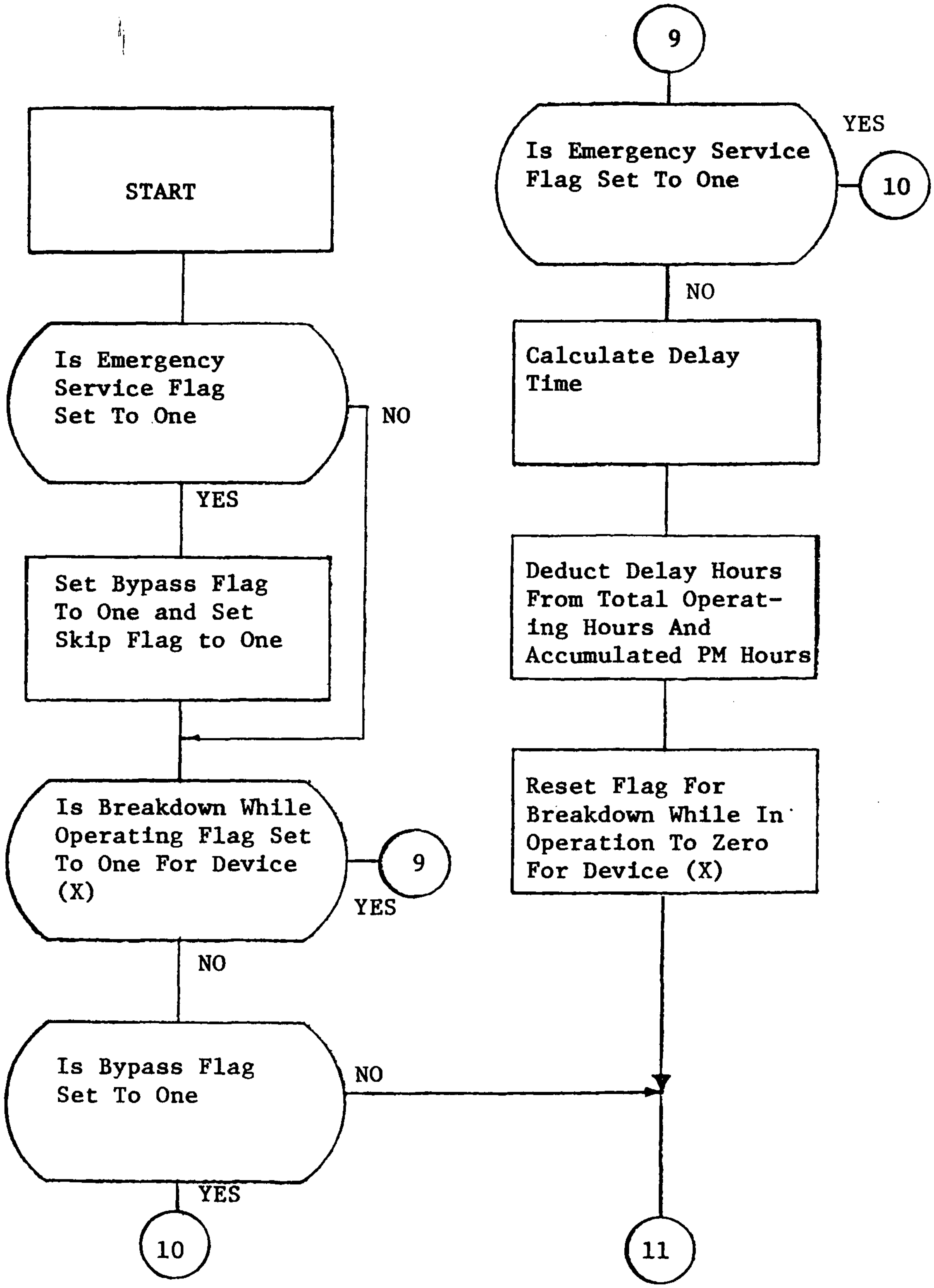

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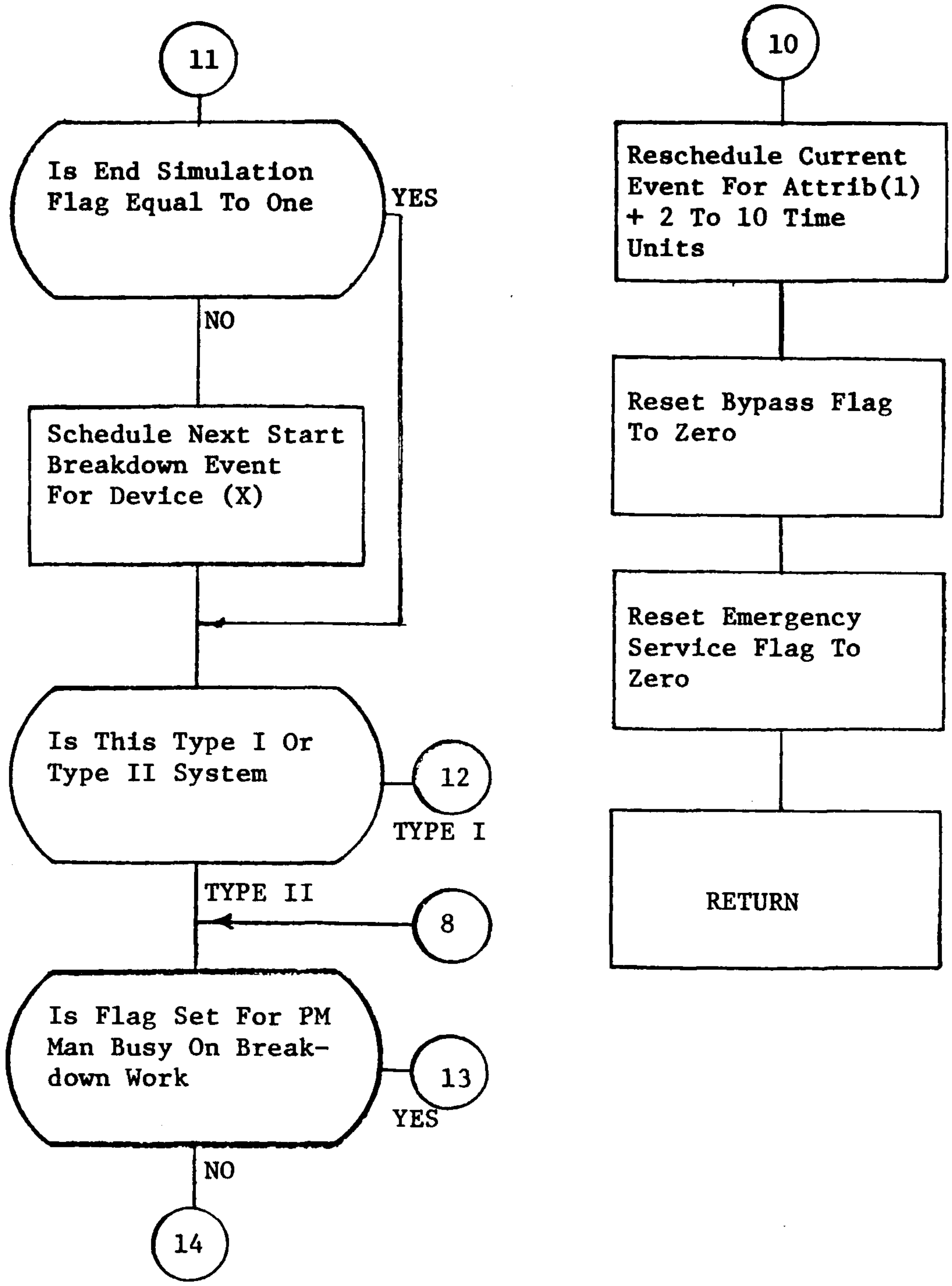
END BREAKDOWN



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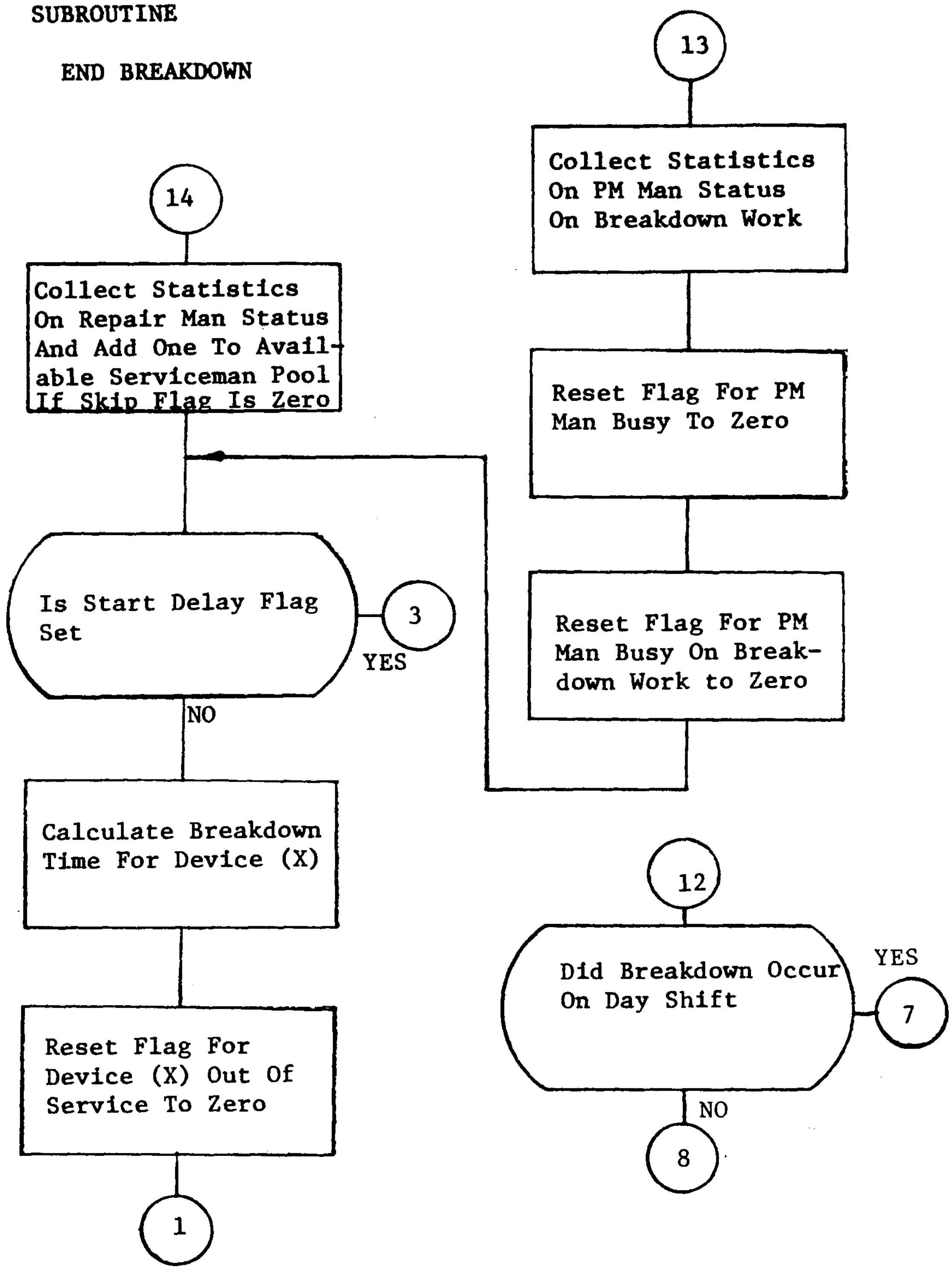
END BREAKDOWN



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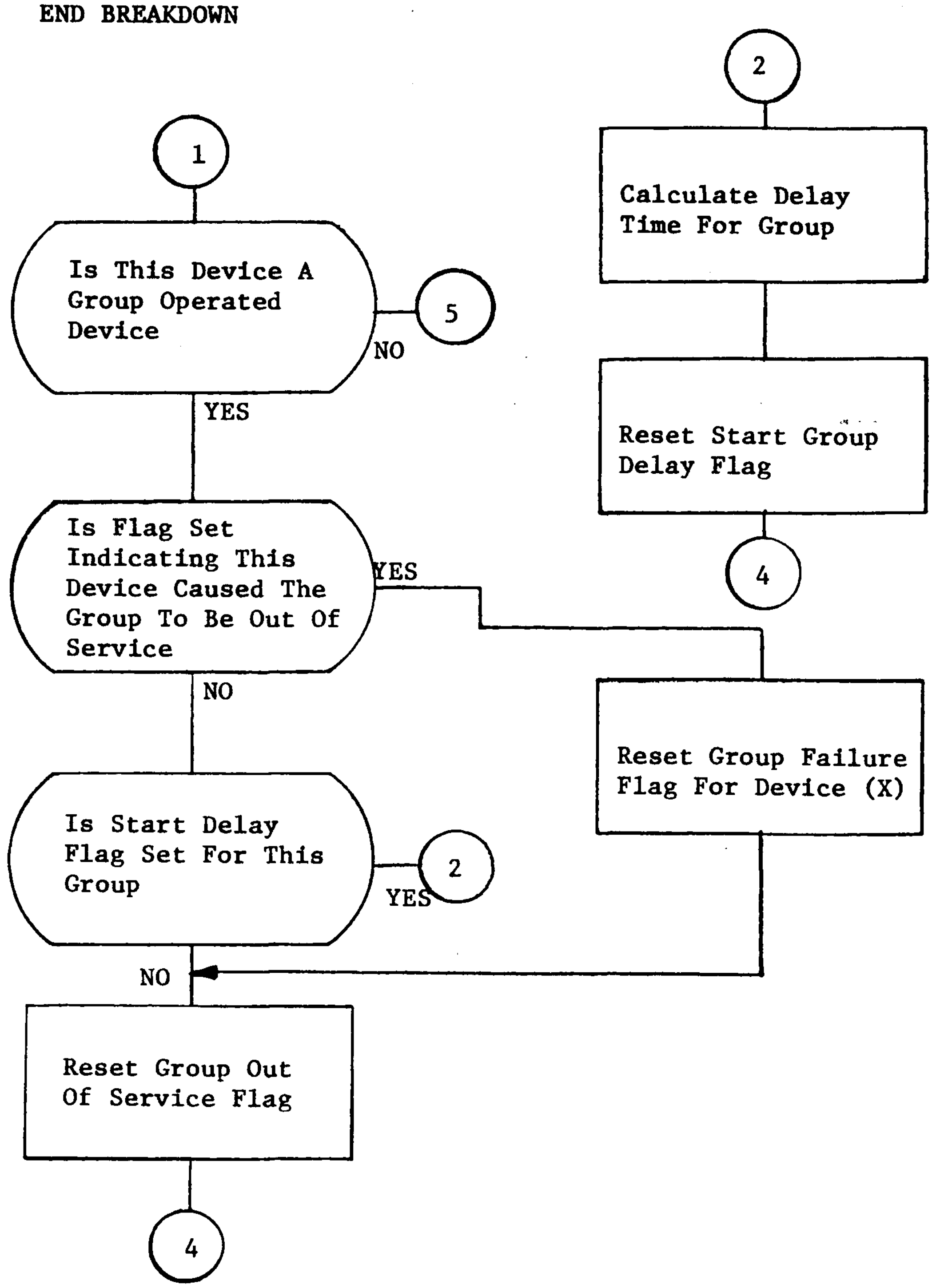
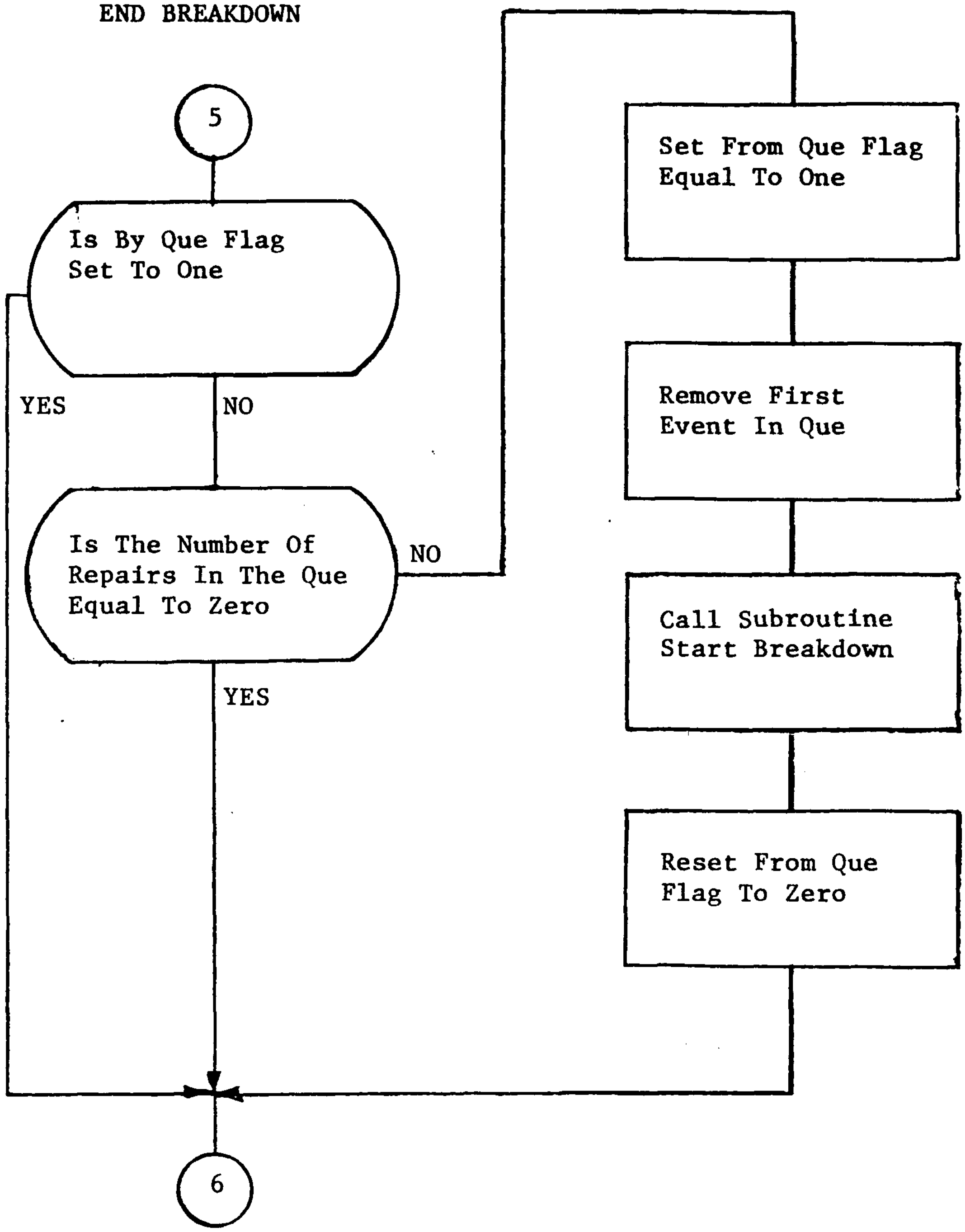
END BREAKDOWN



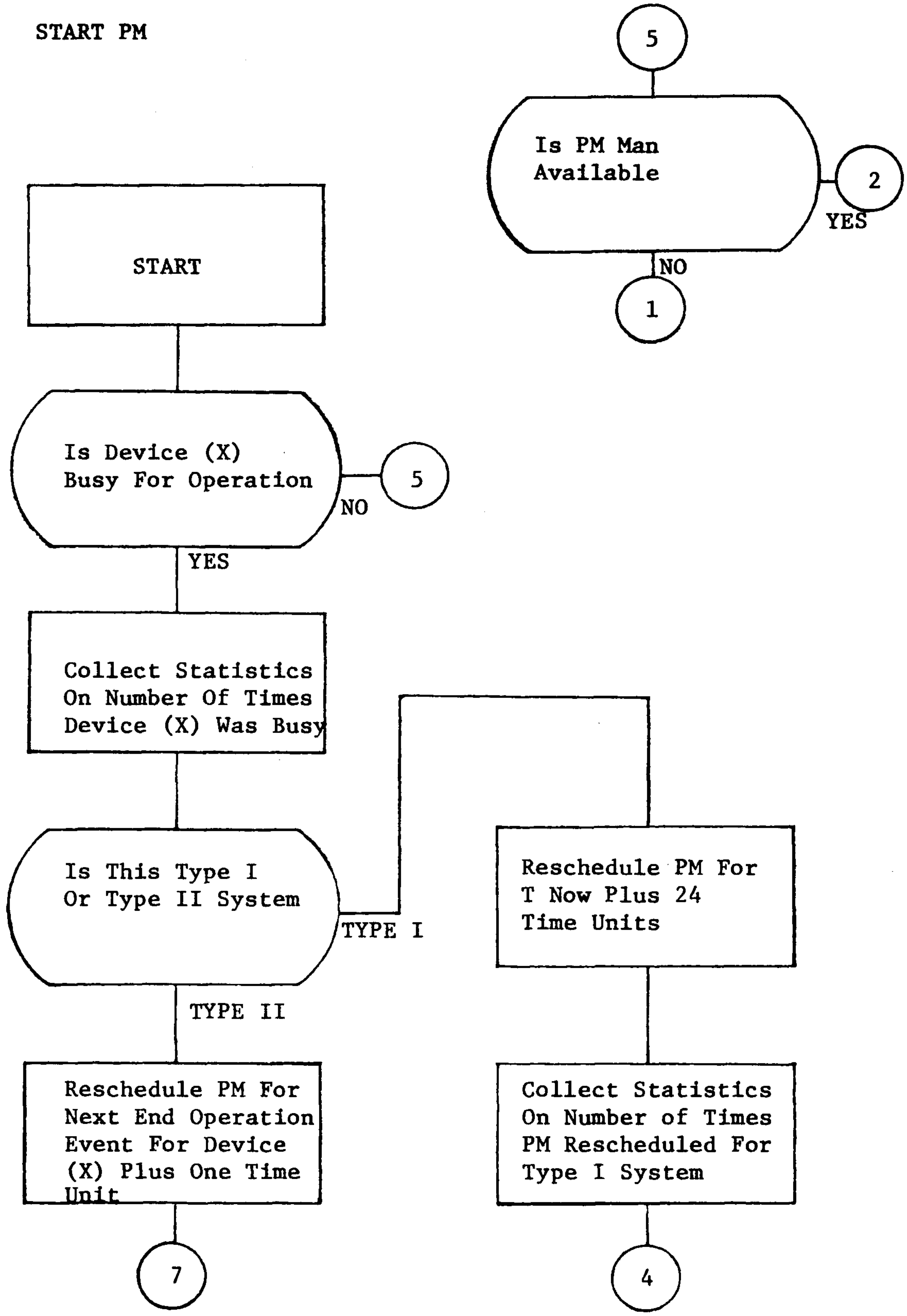
SUBROUTINE

END BREAKDOWN



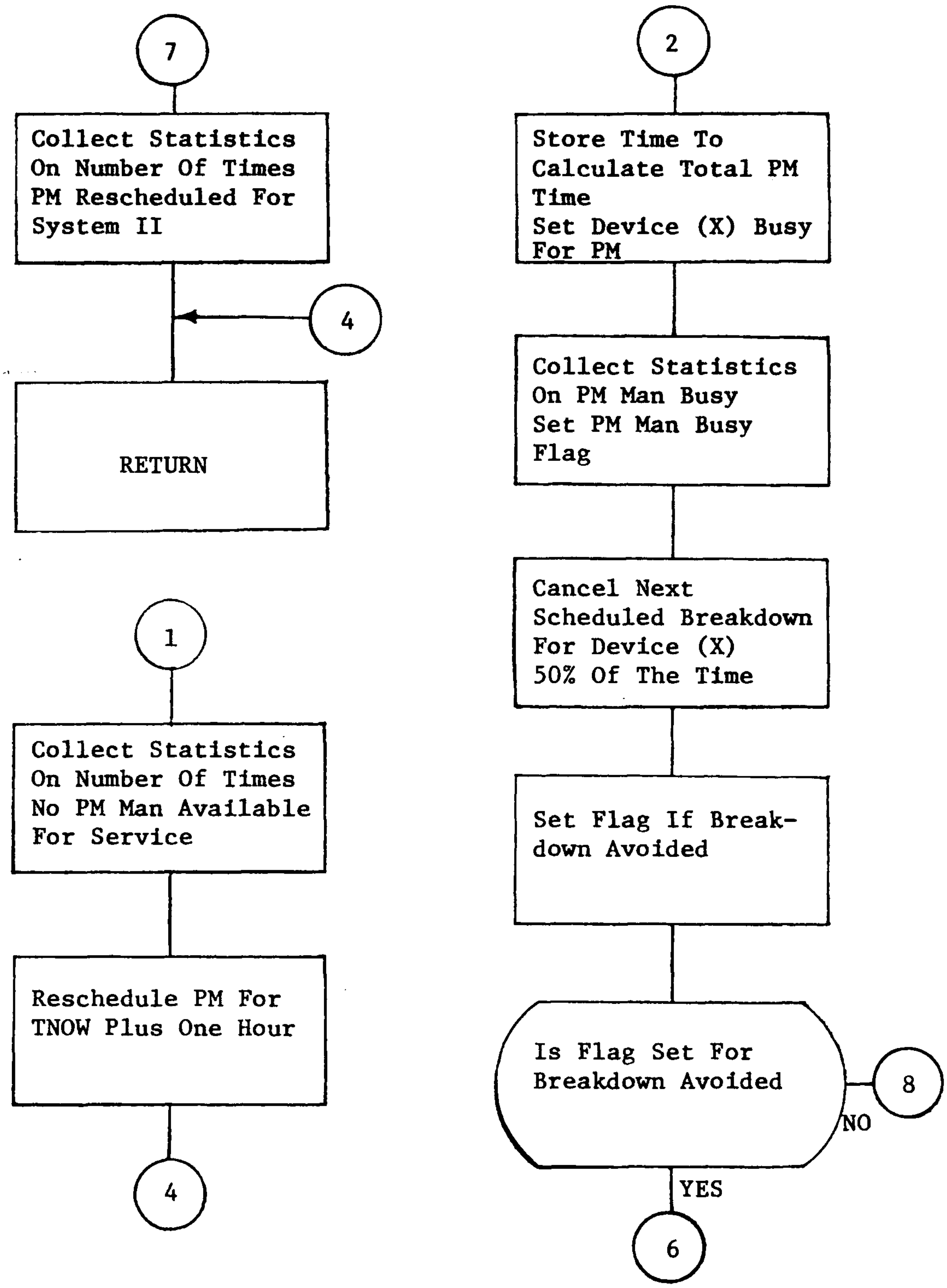
SUBROUTINE

START PM



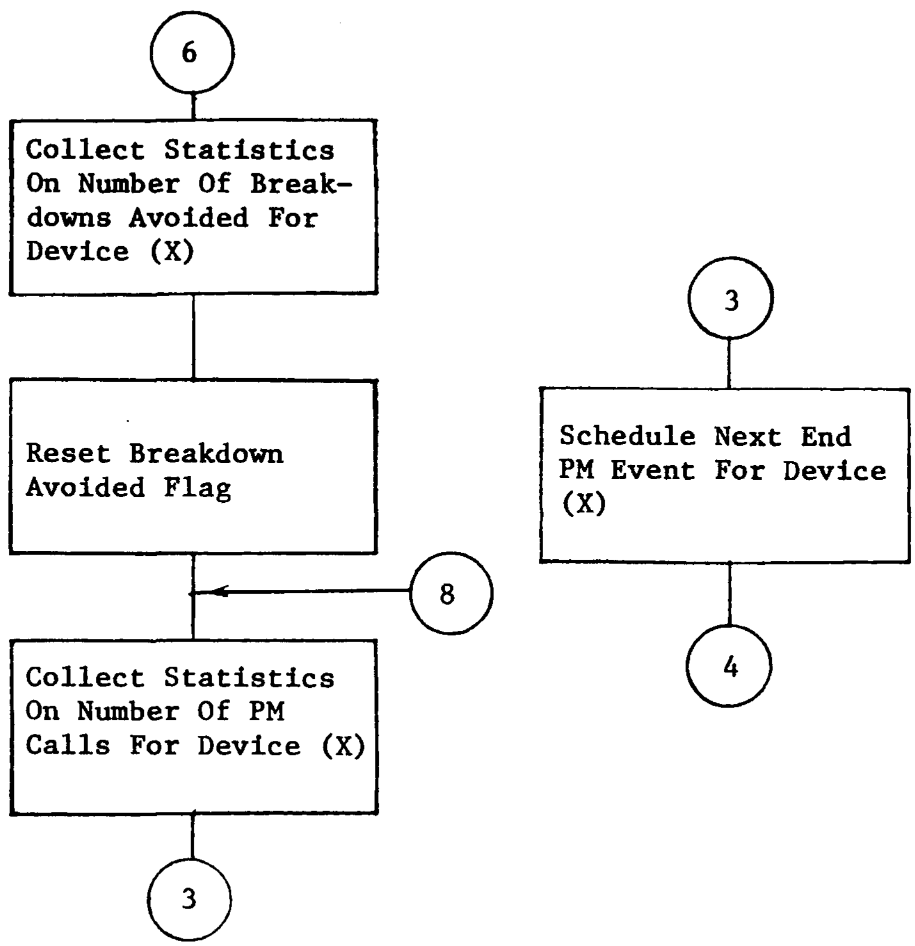
SUBROUTINE

START PM



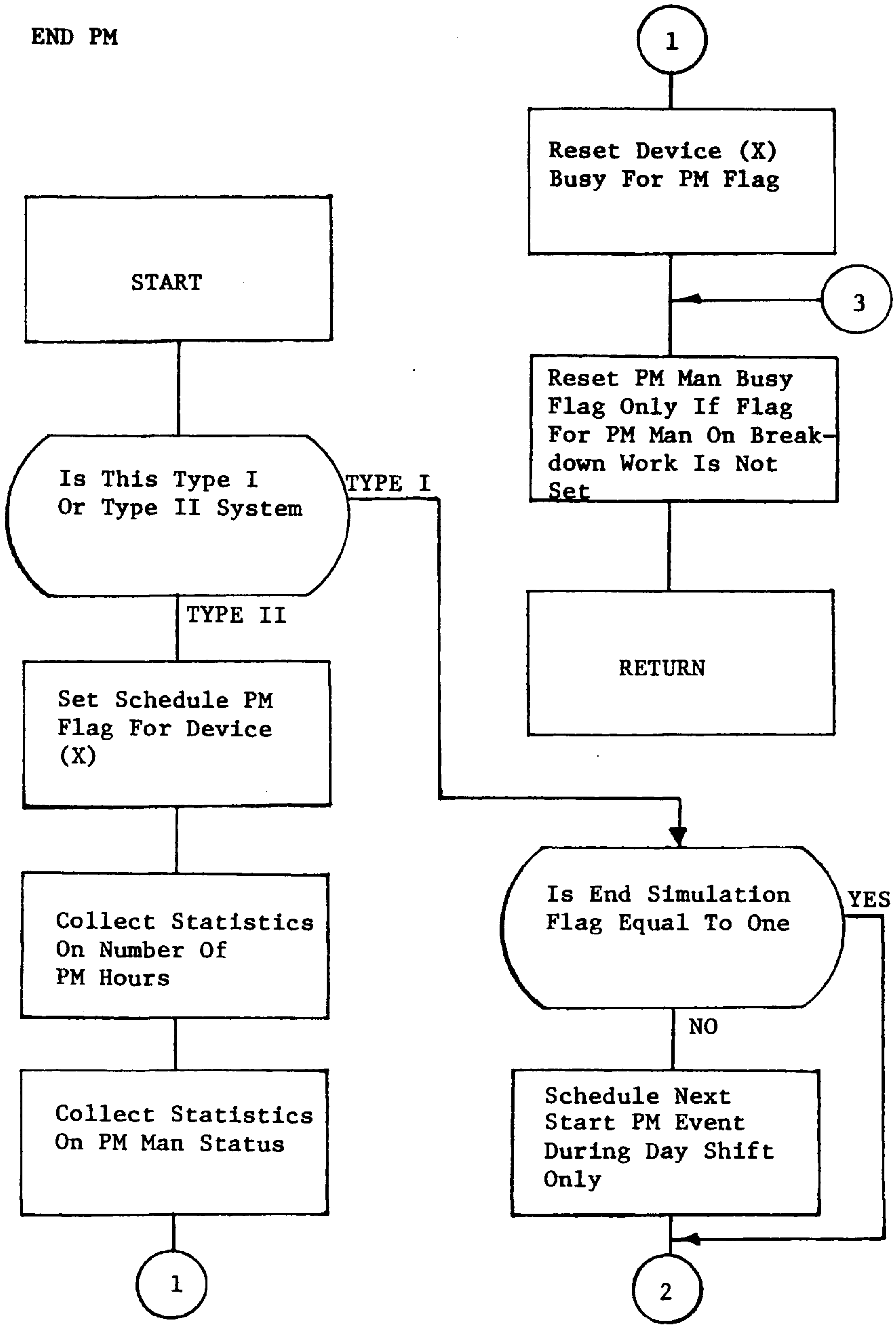
SUBROUTINE

START PM



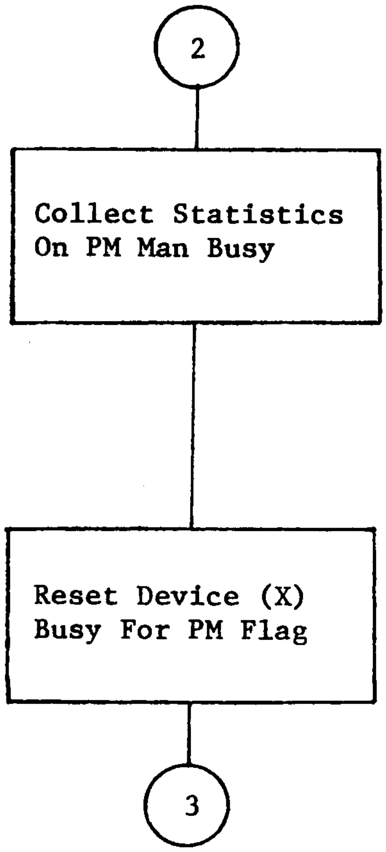
SUBROUTINE

END PM



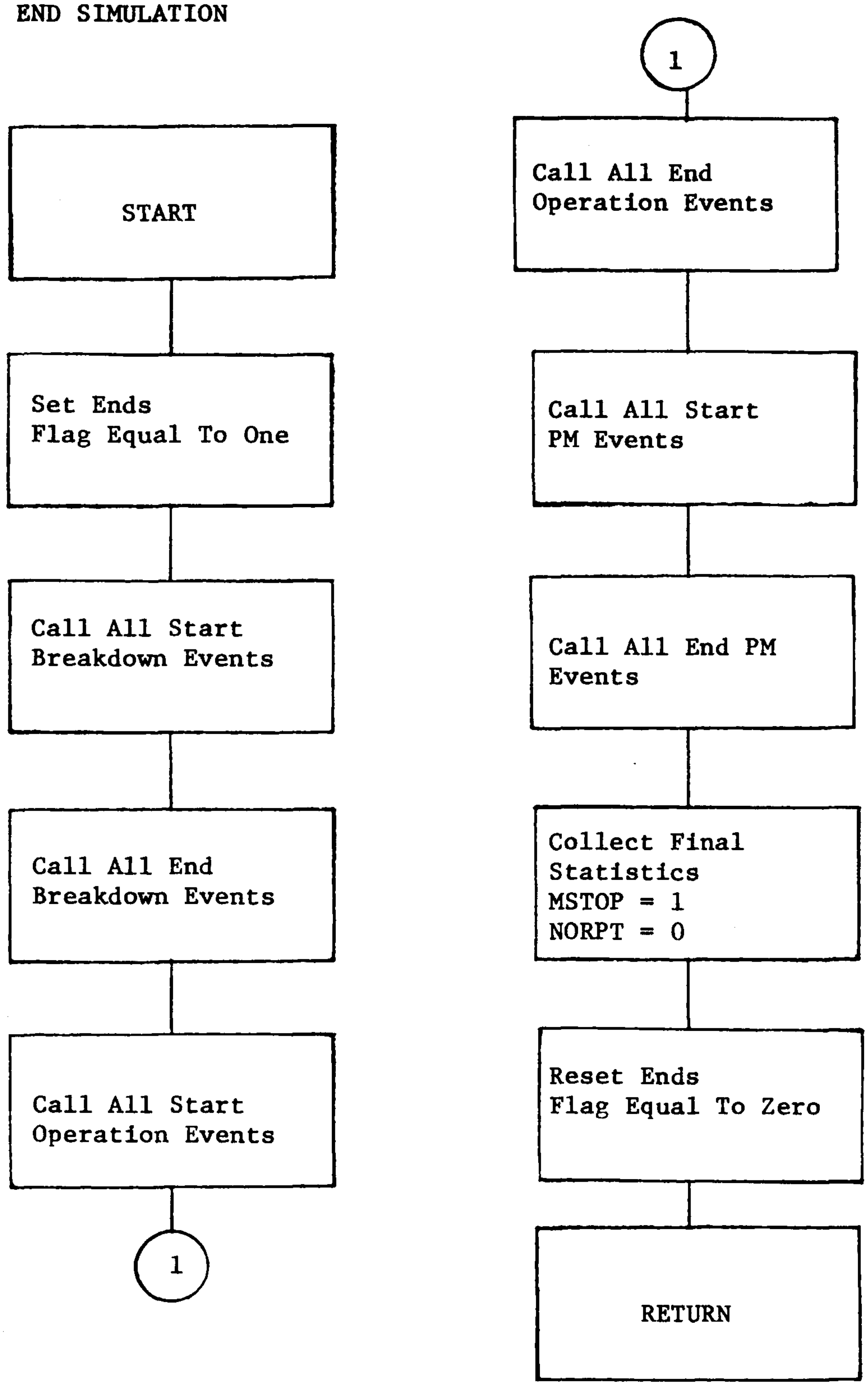
SUBROUTINE

END PM



SUBROUTINE

END SIMULATION



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