A PRODUCTION INFORMATION SYSTEM

by

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Submitted to the Alfred P. Sloan School of Management on May 19, 1967 in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

This thesis is an information system for planning and control of passive production process of the Microelectronics Laboratory of Sylvania Electric. In the planning area the system develops a forecast for the number of additional units which should be started through the production process in order to achieve a high expectation of meeting demand. The basic analysis involves summing the units expected to finish, comparing this sum to requirements and translating any difference back to the initial stage to obtain the additional units to start. In the control area the system generates a series of reports on the status of the in process lots. These reports are the information sources for establishing control in the production area.

The system is computer based. Both the planning and the control functions are implemented through a program which generates the forecast and reports.

The system which has developed in this thesis is an initial step in the formulation of an information system for the entire production area.

Thesis Adviser: Michael Morton
Title: Assistant Professor of Management

Professor Edward N. Hartley
Secretary of the Faculty
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Dear Professor Hartley:

In accordance with the requirements for graduation, I herewith submit a thesis entitled "A Production Information System."

Sincerely,

Signature redacted

Edward Richard Scully

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INTRODUCTION

SCOPE OF THE THESIS

This thesis has evolved from a problem brought forth by the production manager of the Sylvania Electric Mircocircuit Laboratory. The problem as initially presented was how many additional units, if any, should be started to meet finished good requirements and when could the units in process be expected to finish. The inputs were to be the status of the production cycle, that is, the number and location of the units in process. The output was to be the number of additional units to start through the production cycle and the expected finish time for all the in process lots. Initially, I considered only this aspect, but as the system developed, it became apparent that the information required to answer the primary question could be of value in itself as a report of the status of the in process circuits. Thus in the later stages more attention was given to developing the type of reports that would be of use to the production management. In other words, the problem as I saw it expanded from one of finding an answer to facilitate the schedualing of production to one of providing a series of reports detailing the status of the in process circuits, in addition to answering the initial questions. In sum, the system in this stage in its development is an initial step in the formulation of a computer based information system for the production area of the Microelectronics Laboratory.

ORGANIZATION

The introductory chapter of this study of the information system for production planning and control deals with the microelectronics industry and microcircuits in general. The significant characteristics of both monolithic and hybrid circuits are discussed. A general picture of the production and quality control functions for hybrid circuits is also given. Chapter II is a discussion of planning and control systems built about the framework presented in Planning and Control, A Framework for Analysis by Robert Anthony. The emphasis in this discussion is directed towards operational control, the functional area of the proposed system. Chapter III turns to the more specific topic of planning and control for microcircuit production. The planning section defines the variables, the controling decisions and the information needs of the system in addition to specifying the type of analysis to be used. The control portion covers the information needs and the types of reports required to facilitate production control. Moving into the details of the system, Chapter IV presents the several analyses used in the planning phase and a description of the system program. The several analyses include a yield analysis, a unit count analysis and an error analysis. The program description is a detailed discussion of the system program. The final section, Chapter V, discusses the results of the simulated operation and outlines future study.

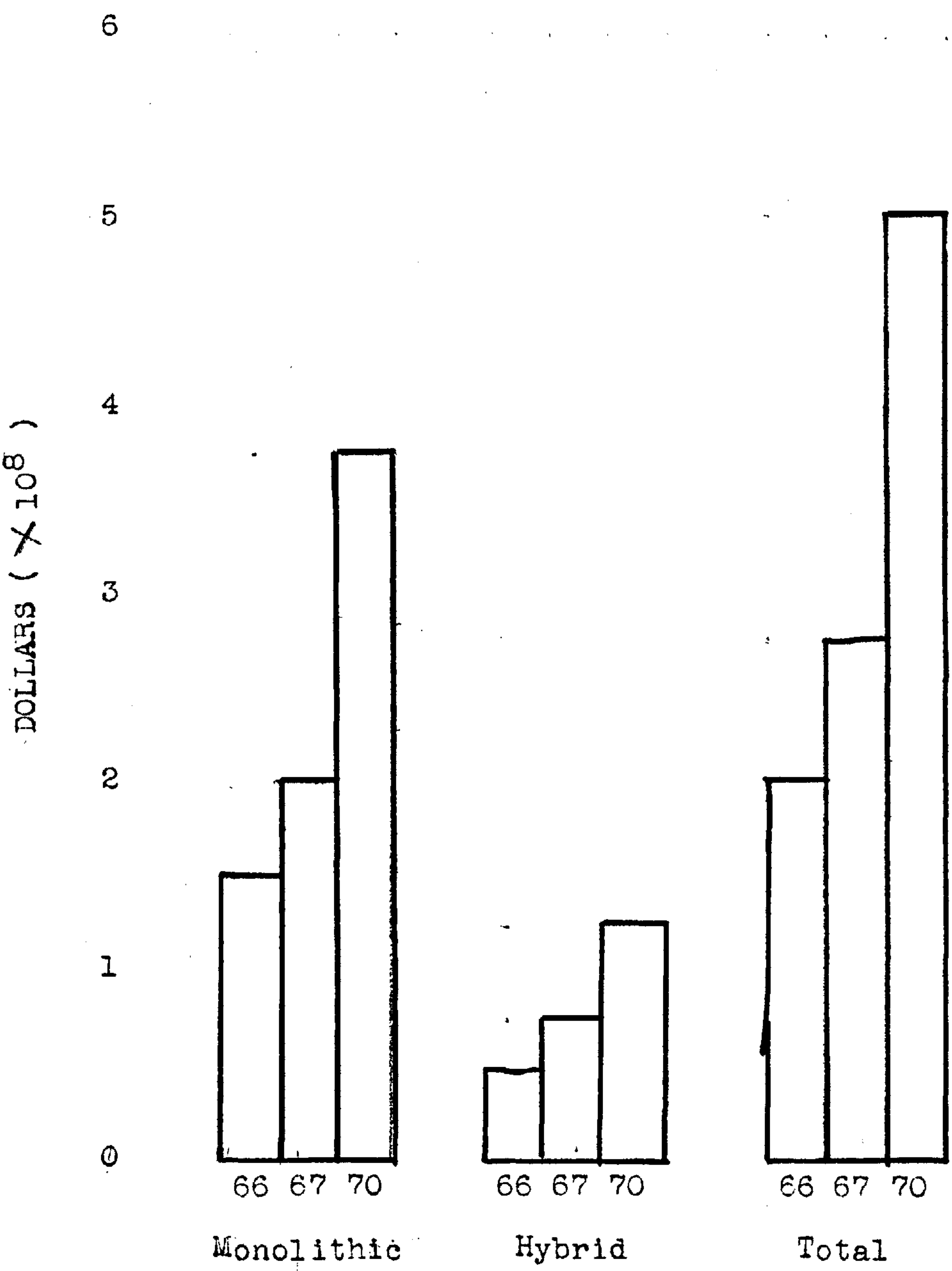
MICROELECTRONICS

The Microelectronis Laboratory of Sylvania Electric is a recently formed section of Sylvania Electronic Products and is responsible for the production of miniature electric circuits. Originally the section served as a support facility for Sylvania Electronic Systems, a division primarily doing government work. However, when the demand for miniaturized circuits increased, the Laboratory took on large volume production operations and was brought under the control of Sylvania Electronic Products.

Currently the Laboratory is in the midst of a period of rapid growth as pointed up by the fact that the facility is expanding by factors per year rather than percent. This rate of growth is indicative of the microelectronics industry as a whole. Chart II is a representation of the projected growth patterns in this industry thru 1970. This growth rate is due to the expanding range of uses to which microcircuits can be put. Currently they are used primarily in military applications and those areas requiring extremely small electronic circuits (such as

CHART I

MICROCIRCUIT SALES



a totally in the ear hearing aid). Yet as the price of the circuits falls, new markets can be expected to open up in the commercial area, particularly in computers, television, and electronic apparatus where size and weight reductions would be advantageous.

MICROCIRCUITS

The heading integrated circuits (or microcircuits) can be broken down into two subheadings, monolithic integrated circuits and hybrid integrated circuits. Each device is a complete electric circuit in and of itself with miniturization being the dominant characteristic; however, there are important size, weight and performance differences between the two classifications.

The monolithic integrated circuit is a complete electronic device fabricated on a chip of silicon only a few hundredths of an inch square. The minuscule units contain the equivalent of dozens of interconnected electronic parts-transistors, diodes, resistors, capacitors-and in many cases they will replace these conventional components. The advantages of these circuits are such as to dramatically change circuit design. First, their microscopic size and weight permits reductions of 10 to 20 times in the size and weight of electronic equipment. Secondly, when mass produced the cost of a monlithic circuit can drop below the cost of the conventional components it replaces. This could lead to not only smaller units but also cheaper ones. Thirdly, these circuits are highly reliable which will help to improve the overall performance of electronic equipment. Fourthly, they use fractions of a volt or ampere and, consequently, produce very little heat. On the other hand, they do have their drawbacks. First, if one component of any type fails the circuit itself must be scrapped. In addition, due to the microscopic size, location of the failed circuit could be a distinct problem. Second, monolithic circuits are good for digital circuits whose function is primatily to emit a signal or not. However, in analogue circuits, which modify or amplify the signal, the need for a relatively larger number of passive components creates the problem of contructing these components on silicon. Third, circuit characteristics and performance are more difficult to control. Thus, when exact outputs are required, different circuit design is required.

Moving to the second area, that of hybrid circuits, one sees an order of magnitude increase in size and weight but advantages in other areas. In contrast to the monolithic circuits, in which all of the components and connections are created in one continuous production process, hybrids are manufactured in several distinct separate steps. First, the connections and the passive components (resistors and capacitors) are painted on and baked to the circuit substrait. Then serarately manufactured active devices, such as transistors, are bonded into place. Additionally all passive circuits can be made by processing only thru the passive area. The advantages of the hybrids are essentially a compromise between monolithic and conventional circuits. First, the hybrids are small both in size and weight. A complete radio transmitting circuit is about one inch wide, one and one-half inches long, and ¼ inch high. Second, the circuit characteristics may be more readily controlled thus permitting more accurate outputs. Third, these circuits are faster than monolithic circuits which is an important consideration in the next generation of computers. Four, these circuits can perform more complex analogue functions than the monolithic circuit. This will permit a wider range of application. In sum, the monolithic circuits will be used where an absolute minimum in size and weight is required, such as the hearing aid, while the hybrid circuits will find wider application in areas where, though size and weight are significant parameters, the accuracy and speed of the output are more important.

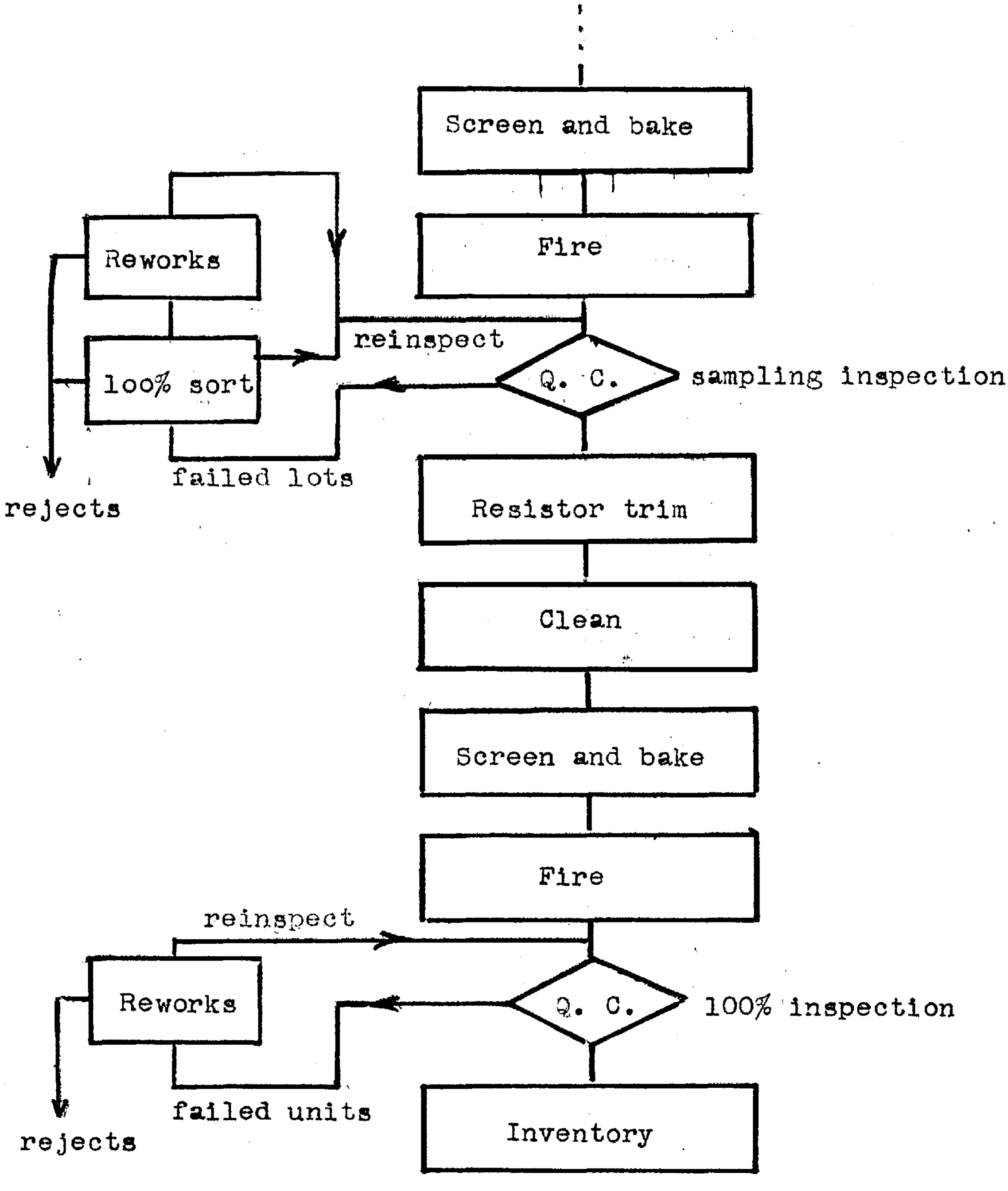
PRODUCTION PROCESS

The Sylvania facility produces the hybrid integrated circuits in two distinct separate processes, passive and active. At any one moment in time there may be several different types of circuits in process. These circuits differ in the number and complexity of passive components and the number of active components to be attached. However, each circuit must pass thru the same general production process, first passive, then active.

In the passive area the microcircuits are processed thru the production cycle in lots of a thousand or more. The circuits start as ceramic substraits onto which are screened numerous planes of passive material. After each screening the substrait is baked and fired to fix that particular plane of material to the surface. With the application of ten or more successive layers, the circuit has a complete set of its passive components. When all the layers have been applied, the resistors are trimmed to obtain the required resistivity between nodes. Following this the circuits are given a protective glaze and then dipped in solder to form pads which are used as connectors for the active components. After a cleaning the passive cycle is complete, and the finished passive circuits go to an in process inventory from which they move into the active cycle.

The active production process is organized about single unit flow. During this process the passive unit is built up with its active components--transistors, coils, and special components--at several locations. The circuit may have a transistor attached at one station

SEGMENT OF PROCESS FLOW CHART



and then move to the next station to have a special capacitor attached. In this manner a unit moves thru the cycle gradually accumulating its active components. At the completion of the cycle a protective plastic is put over the circuit and it is moved to the finished goods inventory.

QUALITY CONTROL

An important phase of the production operation is quality control. A complete hybrid integrated radio circuit is a complex unit, and there are numerable possibilities for error. To insure high quality there are five inspection stations in both the passive and active lines. Inspection consists of both a visual check and an electrical one; failure of either means a failure of the unit. In the passive area quality control is on a sampling basis. A lot either passes or fails depending on the number of defects found in the sample. For example, the typical sample is 80 units of which 60 are good and 20 are faulty. Of the 20 faulty circuits perhaps 15 will be repairable and 5 will go to scrap. With a sample such as this the lot would be rejected, 100% sorted (good, repairable, and scrap) and returned to production. Additionally, at all stages the production section will sort out any units which are obviously defective. As a final control, all units are inspected at the final station in the passive line.

The quality control stations can be looked at as sensors of the state of the system. It is through these stations that the operations manager is able to determine that is occurring on the production floor. Low yields indicate the need for action and point to the area requiring attention. High yields indicate operation well within quality and design specifications but do not look at efficiency. For this system the quality control points will be used as the information gathering points. This is done because all of the required information is already in existance at these points and they are located evenly throughout the process. Thus, to implement the system, no additional information need be obtained and no changes made in the process.

PLANNING AND CONTROL SYSTEMS

In his book, Planning and Control Systems, A Framework for Analysis, Robert Anthony classifies the planning and control functions into three groupings, strategic planning, management control, and operational control. The set of three systems are all percieved to be "complex units formed of many often diverse parts subject to a common plan or serving a common purpose." These systems are the structures which facilitate the implementation of a process; that is to say, the system is the means by which the process occurs. Moving up the scale from operational control to strategic planning, the process, or the way of doing things, becomes more important, while moving in the opposite direction, the system becomes the most important factor.

The definitions of the three sets within the systems framework are given below to point up the distinctions between the levels of planning and control. Strategic planning is defined to be:

> "the process of deciding on the objectives of the organization, on changes in these objectives, on the resources used to obtain these objectives, and on the policies that are to govern the acquisition, use, and disposition of these resources."

Strategic planning is a function of top level management, and as implied in the definition occurs infrequently, has a long time horizon and deals with a complex set of valuables. The flow of information is small, predictive and not overly accurate. The end result of the activity is difficult to appraise. Secondly, management control, the functional area of middle management is:

> "the process by which managers assure that the resources are obtained and used effectively and efficiently in the accomplishment of the organizations objectives."

In contrast to strategic planning the control is prescribed, has a shorter time horizon and considers fewer variables. The flow of information is rhythmic, historic and accurate. The decision process focuses on the organization and centers about human behavior; whereas, in strategic planning the focus is on one aspect and centers about economics. Last on the list is operational control which is defined to be:

> "the process of assurring that specific tasks are carried out effectively and efficiently."

The time horizon now is short, and variables relatively few. The flow of information is large, frequent, exact and frequently in real time. As implied by the definition, the focus is on individual tasks and the source discipline is economic optimization.

The control of the microcircuit production process falls under the category of operational control, for the focus is on the efficient and effective production of a product. The policy has been stated that Sylvania will undertake microcircuit production. The resources have been obtained; the people and machines are ready to produce. The only remaining task is to produce effectively and efficiently; that is to produce a needed product at a competitive price. Yet to produce effectively and efficiently implies that an optimum can be obtained. Some combination of the several inputs will result in the lowest cost output and since the source discipline is economics, there is the implication that this combination of imputs to form the output will follow some analytical relationship. The end result of this string of implications is that a set of analytic rules can be devised to obtain an economic optimum; in other words, operational control is programmable.

To program a control function is to devise a set of rules that prescribe the action to be taken under a given set of circumstances. This implies that there is an optimum relationship between outputs and inputs. This optimum can be either (1) the best combination of outputs and inputs when both can be varied, or (2) the combination of resources that well produce the desired output at the lowest cost, where outputs are a given quantity. In the first case, the optimum can seldom be determined objectively, for there is no way to determine the affect on outputs by changes in inputs. There is subjective judgement involved which leads to the area of managerial control. However, in case two the outputs are set and the possibility of an optimum is more likely. However, the absolute optimum is undeterminable, for new and better ways of solving problems are contantly being developed. Therefore, optimum in this case should be taken to mean that combination of resources, out of all known combinations, that will produce the desired output at the lowest cost. If this optimum relationship can be developed, then inputs that should be employed in a given set of circumstances can be described and reduced to rules, that is they can be programmed.

As new and better techniques are developed, there is a tendency for more and more activities to come under the heading of "programmable." This is clear in the case of factory scheduling where formerely a foreman's intuition was used, now linear programming formulates the optimum schedule. Or in the case at hand, rather than guessing how many new units to start, the program will calculate the appropriate amount given cetain decision rules. The characteristics of operational control and some of the contrasts with management control are outlined by Anthony. To more clearly define operational control and distinquish the types of decisions made in it, the discussion will now turn to these charactêristics.

The focus of operational control is on individual tasks or transactions. This is not to say that the control is necessarily simple or restricted to a small segment of activity. Operational control systems can schedule production for an entire plant or schedule airline's activities, both of which are very complex undertakings. In contrast, management control focuses on the whole stream of activities; it reports summaries, aggregates, totals, not specific items.

The structure of an operational control system is rational; that is the action to be taken is decided by a set of logical rules. These rules may cover all aspects of a problem, in which case the function could be completely programmed, or the rules may have only limited applicability, thus necessitating the use of human judgement. The operational control system is complete in this aspect in that a decision follows naturally from the inputs. In contrast, in a managerial control system the decision is not determined by the system; it will signal the need for action, communicate the information to those who must act, and perhaps dedicate the nature of the proper action, but the human must make the decision.

The information requirements for an operational control system have several particular dimensions. Since operational control is concerned with individual tasks, the data often has nonmenetary dimensions; it is expressed in terms of units, man-hours, pounds, etc.. Secondly, the data are in real time; that is to say in a time span such that the data can be recieved, processed, and corrective action taken all in time to influence the environment. Thirdly, the data stream is continuous; whereas in managerial control the specific information is processed only when there is an exception. Fourthly, the data are exact. When controlling a production process, approximate data allows for only approximate control of the events. It is of little use to know that there are about 1000 units ± 100 or so in process.

The operational control system is highly dependent on the word "system." The system gathers the information, processes it and makes the decision about the action to be taken. There is little human intervention in the process. On the other hand, in managerial control the emphases is on "process." The success or failure of the system depends upon the manager and his judgement, knowledge, and ability. The system provides the information but the decision is made by the manager and thus it is the process of making the decision that counts.

The judgement and understanding necessary are two characteristics which have minimum value in the operational control system. The system is objective and functions under a set of rules. When it says "Start 1000 units" no judgement or understanding is required and to follow system instructions is fairly safe. Of course, an understanding of the system, will put one in a better position to detect mistakes but it is not an essential. This is contrasted by managerial control where decisions are subjective and judgement and understanding have maximum value. However, in operational control judgement is needed to monitor and to change, if necessary, the decision rules. One cannot assume that the process will remain the same; there must be continual checks to insure that the system is in fact providing adequate control. If these investigations reveal that the signals deviate significantly from the correct reactive signal, then the decision rules must be modified to fit the true state. It is in this area of revising the decision rules that judgement is used by operations management.

PLANNING AND CONTROL FOR MICROCIRCUIT PRODUCTION

Having discussed operational control in general terms, we now turn to the particular system at hand. The primary purpose of this study is to devise an information system which will be an aid in the planning and control of the production function of the Microelectronics Laboratory. This statement of purpose brings up the question, what is there to plan for and what is there to control? Generally speaking, we plan for the efficient production of Microcircuits and exercise control to insure this efficient production. More specifically, we must plan for scheduling the production of sufficient units to insure meeting the demand for the product. And once these plans have been initiated we must be assured of swift processing through the production cycle, a task requiring good controls. To fulfill the first of these objectives, the information system must develop an answer specifying the number of units that should be started in order to meet the demand. Secondly, the system must provide a status report for all of the lots in process; the function of this report will be to enable the operations management to control the processing of the lots more effectively and obtain greater efficiencies. These are the overall objectives, which must be analyzed to determine the information needs to fulfill the objectives.

The information needs of the Microcircuit facility are best investigated by determining the key variables within the facility. Having determined these valuables, the logical second step is to isolate the decisions which control these key areas. Then this set of decisions can be examined to discover the information required to effectively make the decisions. Yet the information alone is insufficient; for to be of any use it must be subjected to some form of analysis. The third step is thus the formulation of the type of analysis that the information must be subjected to. The final stage is a check to insure that the particular combination of information and analysis will lead to the set of decisions which will adequately control the key variables which, in turn, will lead to the effective and efficient operation of the facility.

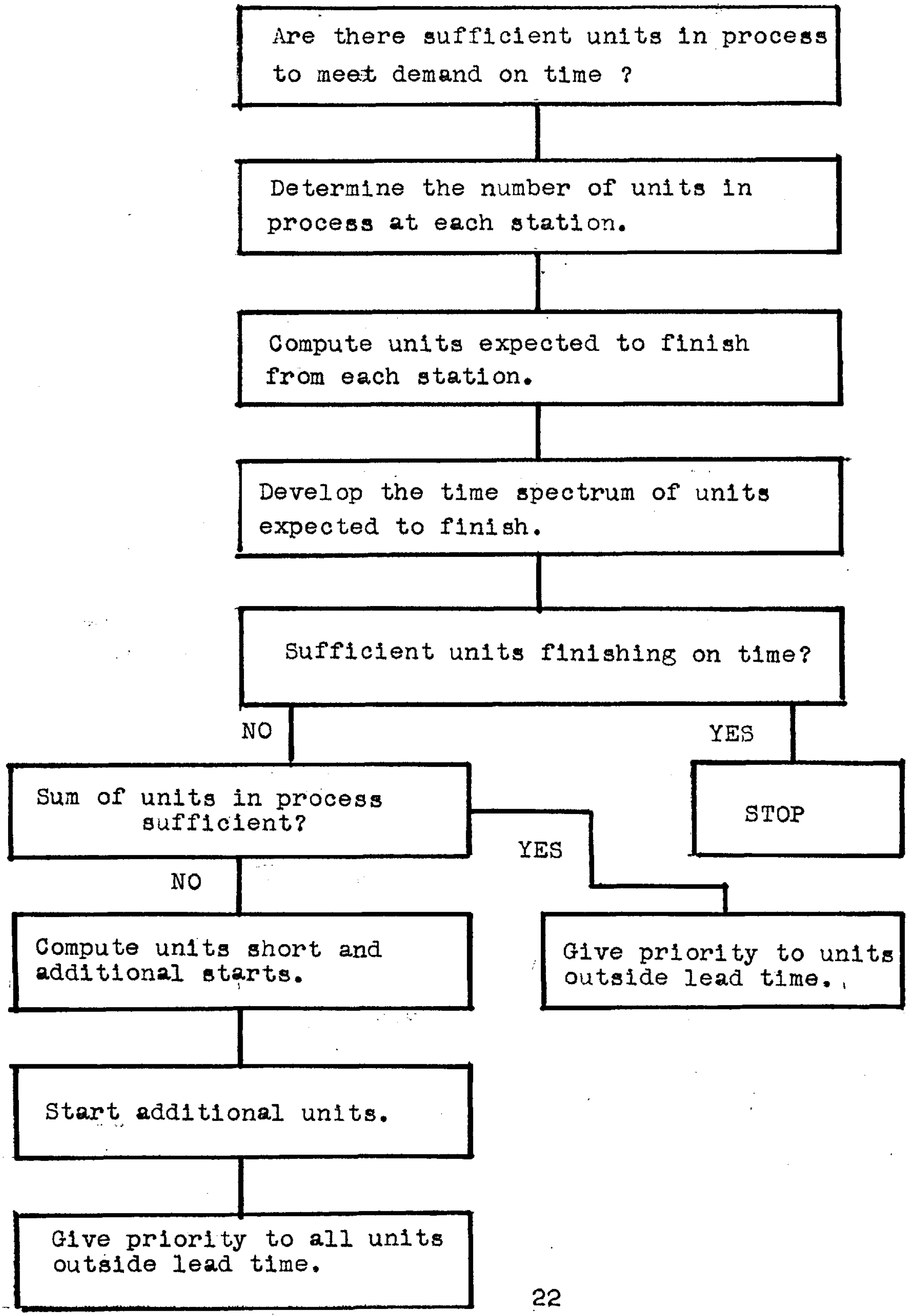
PLANNING

A key area which stands out as a region of prime importance is the delivery schedule, or in more general terms the demand for the microcircuits. The delivery schedule is the key for it determines the level of activity within the plant. Though from the overall point of view, this is more an area for management control, once the contracts have been signed and the delivery schedule set, the responsibility falls to production management to meet the schedule, at the lowest cost within design and quality limits. In other words, the goal of the operations management is to seek an optimum about three parameters, cost, quality and design, given that output is fixed. To attain the optimum requires that sufficient units be scheduled for production and that the production process be expedited to insure that the units will finish within the lead time.

Having decided that the delivery schedule is a key variable, the next step is to determine the decisions which control this variable. This decision process in initiated by asking the question, "Are there sufficient units in process and will they finish on time to meet the delivery schedule?" An answer of "yes" will put off any further action until the next cycle, while an answer of "no" will prompt a decision as to how many more units to begin or where the emphasis should be placed so that the delivery schedule can be met. Thus the decision boils down to the statement: "We must start X units to meet our delivery schedule." or "We must give priority to these units to insure bringing them within the lead time."

With the key variable identified and the decision process isolated, the information required to make the

DECISION-MAKING FLOW CHART



decision must now be investigated. To say that X units must be started, assumes that the status of the production process is known in detail. Specifically, the following is a listing of the information about units required to make the controlling decisions:

(1) The number of units in process at each stage in the cycle

(2) The status of the in process lots:

  (a) The number of units accepted in the quality sample

  (b) The number of units rejected in the quality sample

  (c) The number of units sent for rework in the quality sample

  (d) The number of units scrapped by the production department

  (e) The number of units started in new lots

(3) The number of units required for delivery

(4) The inventory on hand

Additionally the following system constants are required:

(1) The average yield for each of the quality control stations

(2) The expected production time from each station to inventory.

Yet the information alone is insufficient, for the picture is not clear as to whether the delivery schedule will be met or not.

To obtain meaningful signals, the detailed information must be subjected to a form of analysis that will permit the production manager to state with a degree of certainty just how many additional units must be started or which lots should be given priority. This analysis is developed in two stages, first, the number of units expected to finish from each stage, and second, the summation over the lead time of units expected to finish.

The number of units expected to finish is derived from a simple yield calculation at each information gathering station (in this case quality control points). At any point in the production cycle, the number of units from a particular lot that can be expected to finish is computed by multiplying the number of units in the lot by the expected yields at each of the remaining quality control stations. As an example, a lot of 1000 units having yet to pass 3 quality control stations with average yields of .9, .8 and .8, respectively, can be expected to finish with approximately 1000 x .9 x .8 x .8 or 576 units. However, the number of units expected to finish is insufficient in itself, for the expected finish time must be included to insure meeting the delivery schedule.

The expected finish time is at best a guess of the average length of time for a lot to move from any point in the process to inventory. The figures are derived from general estimates as to the length of time to process a lot through each operation. The total time is the sum of the individual operation times. Since production delays are difficult to forecast, the estimates contain no allowance for delay; only normal production times are considered.

With the combination of both the number of units expected to finish and the expected finish time, a time spectrum can be developed showing the number of units expected to finish at any given time. With this spectrum, the production staff will be able to answer the question "Are there sufficient units in process to meet the delivery schedule?" By looking back into the time spectrum as far as the lead time and summing the units expected to finish, the total number of units expected to finish within the lead time can be determined. If this number is insufficient, then by looking further back into the spectrum, the staff can determine at what point there will be sufficient units expected to finish. Those units outside of the lead time will then be given priority in the process in order to bring them within the lead time. In the extreme case, where the total of all units expected to finish is insufficient, then an order can be placed to begin more units to meet the demand. The number of additional units will be the number of units that the system is short divided by the overall process yield. If the additional starts are small, then they can be added to the next scheduled lot. If they are large, then they can be started as a separate additional lot.

The above system is based on a lead time shorter than the total length of the production cycle; to add more buffering to the system, the lead time can be set longer than the cycle. Inventory will thus be built up but at the same time the chance of not meeting demand will be decreased. Increasing the lead time can be easily done for the demand is fixed; the contracts call for a set amount to be shipped each week. Thus instead of looking only at next week's requirements, the system should look at the next three weeks requirement. Three weeks lead time is chosen as the production cycle is approximately two weeks plus a coupleof days. Under this more buffered scheme, the system will be able to more readily handle yield fluxuations.

One of the significant characteristics of micro-circuit production is the difficulty in determining product quality by visual examination alone. Though some defects can be picked up visually, many must be determined electrically. As a consequence, the quality of a lot can be low yet go unnoticed until the quality control station. Since several days production separates each quality control station, a low yield lot can be in the system that period of time without being noticed. The consequence of of this is that the value for units expected to finish is overstated. This is not too important at the initial stages of production for new units can be started with little loss. However, if the production fault and resultant low yield are at the end of the cycle, the chance of not meeting demand becomes higher. Yet with a sufficient lead time even a poor yield at the last stage can be smoothed. The smoothing process will involve recalculating time spectrum of units expected to finish. As before, the number of additional units required can be started. If the number is small then they can be added to the next scheduled lot; if disaster has struck and a lot is essentially wiped out, then a supplementary lot can be started.

This entire process can be reconstructed as a flow analogy. Consider a pipe with a flow velocity such that it takes 12 days for any one cross section of fluid to traverse the length of pipe. At certain intervals there are leakages (ie. quality stations) and the amount which leaks out per unit time is a variable (analogous to the lot yields). Each of these stations monitors the leakage and reports to a control point which determines if the sum of the leakages is such that more fluid should be added to insure that enough fluid reaches the end of the pipe to keep the reservoir full.

The final stage of this discussion is the evaluation of the string of cause and effect relationships. The information system has monitored the flow of inprocess goods, an analysis has been performed on the data, and a report has been issued rating the adequacy of the inprocess units. But the question must be asked as to whether the proper corrective action is taken when this system is employed. At present new lots are scheduled on a regular basis, but there is no clear indication as to whether the new lot should be started, if they will be adequate, or what the correct number of units to start is. This system gives the number of additional units to start given certain expectation (average yields) and requirements (system demand). In addition, it provides complete information in regard to lot status. Whether the signal given is the correct one is a function of the accuracy of the constants. For example, if the average yield values, the ones used to calculate expected finishes and additional starts, are in error, then the signal will also be in error. Thus the use of the system must be tempered by the accuracy of the constants. A further discussion of this error will be covered later.

CONTROL

A second function of this system involves the usage of variable resource inputs such as materials and labor. In part, operational control is defined as the efficient performance of a task; efficient production implies that the product will be made at the lowest cost, given quality and design constraints. Thus an objective of the production staff is to produce the circuits as efficiently or inexpensively as possible. This can be accomplished by keeping the yields high and making efforts to reduce costs. The reduction of production costs is not in the realm of this thesis; it is a task for the engineers. However, since the information system monitors the production process, it can be employed as a device for pointing out trouble areas.

The decision which controls the variable is a consequence of asking the question: "Could this section of the production process be improved such that the process will become significantly more efficient after the change?" Three answers are possible. To answer "yes" would call for action while "no" would stop the search; an answer of "maybe" would call for a closer look at the problem. Having decided what decision must be made, the next step is to list the information requirements.

To discover trouble areas in the process, one must have detailed information regarding the inprocess circuits. The information required is much the same as for the delivery schedule, except that certain parameters can be neglected. The listing of the information needs is:

(1) The number of units in process at each stage in the cycle

(2) The status of the in process lots

(a) Number accepted in the sample

(b) Number rejected in the sample

(c) Number sent for rework in the sample

(d) Number scrapped by production department

(3) The average yields at each station.

With this information the analysis can now be performed to point out trouble areas.

As was done in the previous section, a yield analysis is performed on the data. For each product at each stage a record is kept of the yields. By plotting these yields over time certain trends can be picked up. With a continually improving yield picture no action need be taken. However, if the yields are consistantly low or fluctuate widely, then that section of the process should be investigated to determine the cause. Likewise, if at yield point N the values are erratic while at N-1 they are consistantly high, the problem area has been narrowed to the region between the stations. With searches such as this the problem areas can be worked out of the process leaving a more efficient production process.

A third and important function of this system is simply to maintain an orderly record of the status of the in process lots. The management must know what lots are in process, where they are, and what is happening to them. This information system will be able to answer all of these questions. By referring to the section of the report covering the product in question, the operations manager can see at a glance the status of all the lots in that product group. Additionally he has available a summary statement of the processing results for the product on that day.

At present the operations manager gathers his information from several sources, but he has no concise report from which he can determine the overall picture of the production cycle. Using this system, modified to include points other than yield stations, can give him this overall picture. By expanding the number of reporting stations, a closer check can be maintained on the in process lots. A system such as this would report simply that lot 5 was processed through operation 17 today and there are 800 units in the lot. Presently the system can accomodate input cards such as this but it locates the lot only to the extent that it is somewhere between two inspection stations. Since the inspection stations are several production days apart, this does not fix the lot very well. To modify the system, the number of reporting points can be increased to the point where the exact location can be given for each lot on each day. The report would give the following information:

(1) Station and lot

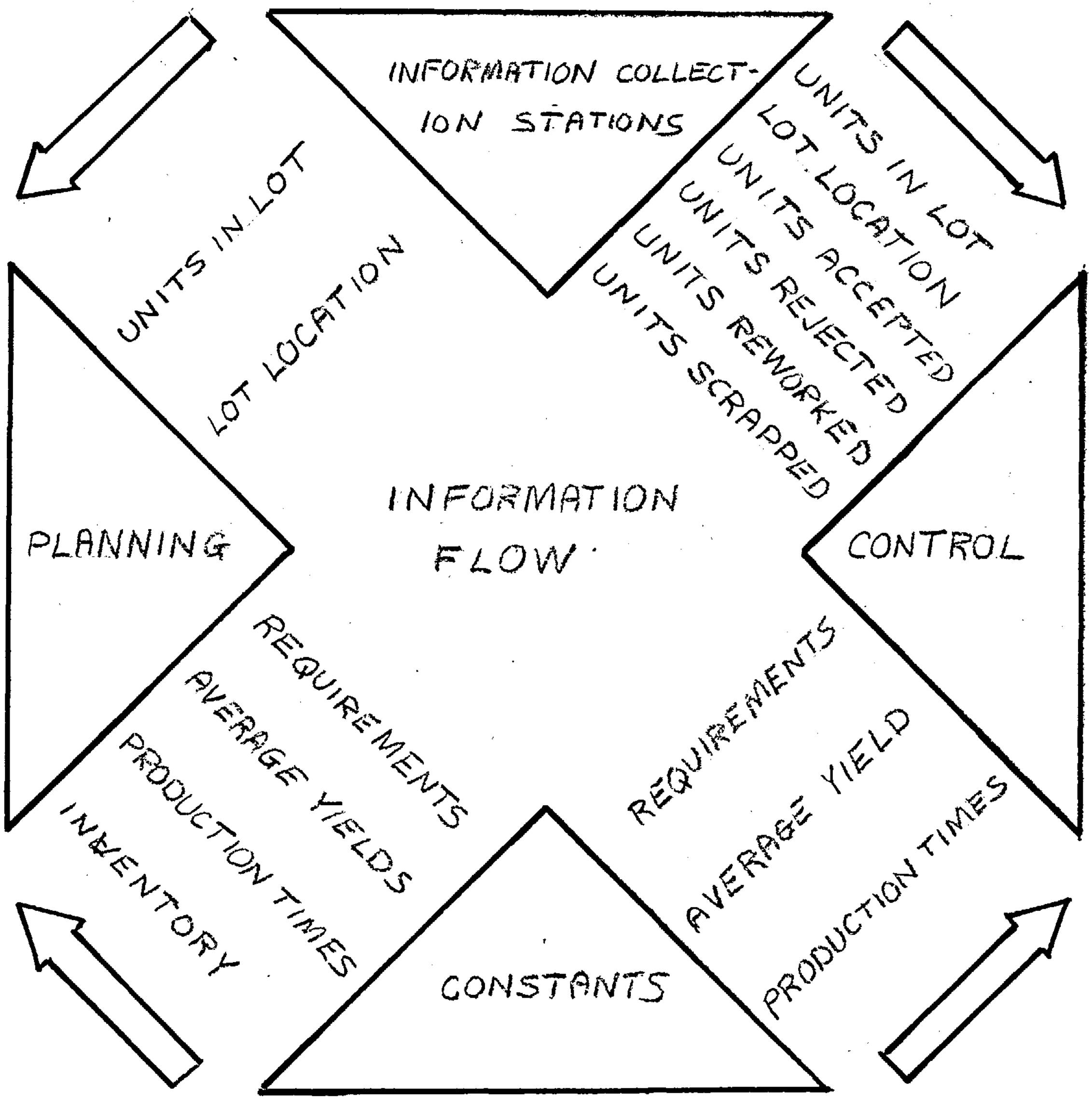
(2) Number of units in the lot

(3) Number of scrapped units being carried

(4) Number of units expected to finish

(5) The expected finish time.

The reports from the inspection stations would remain the same; that is they would include the results of the sampling plus the above information. There are two limitation to this scheme. The first is that the data must be collected each day for each lot in process. Though this is no monumental task (since there would only be a few lots in process at any one time), it will require establishing procedures to insure that the data is in fact collected. Secondly, as the number of information points increases, so does the size of the matrices to record the information. Owing to the computer size, the modified system may bump against the computer core limits. This would necessitate the modification of the program.


INFORMATION COLLECTION STATIONS
UNITS IN LOT
LOT LOCATION
UNITS ACCEPTED
UNITS REJECTED
UNITS REWORKED
UNITS SCRAPPED
UNITS IN LOT
LOT LOCATION
PLANNING
INFORMATION FLOW
CONTROL
REQUIREMENTS
AVERAGE YIELDS
PRODUCTION TIMES
INVENTORY
REQUIREMENTS
AVERAGE YIELD
PRODUCTION TIMES
CONSTANTS

ANALYSIS AND DESCRIPTION

ANALYSES

The preceding chapter brought up the need to analyze the information to obtain meaningfull signals from the system. This analysis is conducted primarily in the planning area. The control function is concerned with what has happened and as such requires only reports on the status of the in process lots. On the other hand, analysis is required in the planning area, for it is here that there is a need for a forecast. The yield analysis fulfills this forecasting function. In essence, it develops the number of units expected to finish from all stations, sums over all stations, and compares the sum to requirements. The difference between the units expected to finish and requirements is the number of units short. The units short are then translated into the number of units to start in order to meet requirements. A secondary analysis in the system checks any discrepancies between the number of units last reported in a lot and the number presently in the lot. This simple comparision of two values and computation of percentage difference falls into the control area. The third analysis in this chapter considers the possible magnitude of error within the system, which is a function of the error in the constants HYLD. Terms are developed giving the difference between the true number of additional units to start and the number specified by the system.

YIELD ANALYSIS

The information recieved by the system from the inspection stations is subjected to a yield analysis to determine the number of additional units, if any, which should be started to meet the delivery schedule. The elements of this analysis are as follows.

The number of units expected to finish from each station is computed using the average yield figures. The equation used is:

$$FNLX_i = X_i \prod_{j=i}^{n} HYLDj$$

where

$FNLX_i$ = the number of units expected to finish from station i

X_i = the number of units currently at station i

HYLDj = the average yield of station j

$\prod$ = operator for series multiplication

n = the number of stations, where the station number increases going down the line.

The total number of units expected to finish is obtained by summing over the total production line. In this case the summation is taken over the entire line because the lead time has been set longer than the production cycle. However, if it were shorter than the cycle, the summation would be taken only up to the lead time. The total number of units expected to finish is:

$$SUMFN = \sum_{i=1}^{n} X_i \prod_{j=i}^{n} HYLD_j$$

where

SUMFN = the total number of units expected to finish within the lead time

The next step is the analysis is to check to determine whether the number of units finishing within the lead time will be sufficient to meet demand.

The demand for finished passive circuits is set by the number of units required for delivery. To determine whether the delivery schedule can in fact be met with the units currently in process, the following equation is used:

$$DELTA = REQ - INV - SUMFN$$

where

DELTA = the number of units in excess of or deficient from the requirements

REQ = the requirements for the length of time equal to the lead time

INV = inventory on hand

SUMFN = sum of the units expected to finish within the lead time

If DELTA is positive, then the probability of not meeting demand is significantly greater than if DELTA is negative, which indicates that from current expectations demand will be met.

Having computed DELTA, the next step is to relate this value back to the initial production stage to determine how many additional units should be started. The translation is accomplished by using this simple relationship:

$$STRT = DELTA\,(\pm)/TTYLD$$

where

STRT = number of additional units which should be started to meet demand

DELTA(−) = number of units shy of meeting demand

DELTA(+) = number of units in excess of demand

TTYLD = overall yield for the production process

The signal given by this system is the number of additional units which should be started to meet the demand. The development of this signal is the product of the three steps discussed above. In concise form the process boils down to translating the units in process to the number of units expected to finish, computing the difference between the units expected to finish and demand, and finally translating this difference back to the number of additional units to start.

UNIT COUNT ANALYSIS

An important segment of the control function is to account for all the in process units. Lost units indicate a lack of close control over the process. To insure good control, a system must, check to insure that all units are accounted for as they move through the production process. To fulfill this function this system has a check to determine if the number of units reported at the current position equal the number reported at the last location. There is a one percent variability allowed due to the large number of units being handled and the chance for a miscount of a few units.

One of the inputs to the system is a matrix of the last reported positions of the inprocess lots, XX(K,-J,M) where K is the product type, -J is the lot number, and M is the last reported position. When an input card is processed, the number of units presently in the lot, X(K,-J, I) is compared to the last reported number in the lot.

$$\text{DIFFERENCE} = X(K, -J, I) - XX(K,-J,M)$$

If this difference is greater than one percent of the number presently in the lot an error message is printed.

This message states the lot number, the lot position, the unit count difference, and the percentage difference. The value used for further computation is the value reported to be presently in the lot, X(K,-J,I).

ERROR ANALYSIS

As previoulsy brought out, the validity of the signal as to how many additional units to start is dependent upon the accuracy of the system constants. Error is introduced into the analysis due to the uncertainty involved in establishing the system constants. This error can best be discussed by considering it as the difference between the assigned value of the average yield and the tru value is the error in the yield figure.

$$ERROR_i = e_i = HYLD_i\ (TRUE) - HYLD_i\ (ASSIGNED)$$

where i denoted the i the quality control station and HYLD is the average yield. In percentage terms the error at the ith station is

$$e_i(\%) = \frac{HYLD_i(TRUE) - HYLD_i(ASSIGNED) \times 100}{HYLD_i\ (TRUE)}$$

The total error in the system is a summation of the errors in the individual stations because in the analysis the units expected to finish are calculated by multiplying the remaining yields times the number of units in the lot. The expression for total error in percentage terms is

$$E\ (\%) = \sum_{i=1}^{n} e_i(\%)$$

where n equals the number of inspection stations. From this it follows that the error in unit count of those units expected to finish from the k th station is

$$\Delta \text{ FINISH}_k = X_k \prod_{i=k}^{n} (\text{HYLD}_i(\text{ASSIGNED}) + e_i(\%)) \sum_{i=k}^{n} (\%)$$

where

Δ FINISH$_k$ = difference between the true and calculated value of units expected to finish from station k.

X = number of units in the lot

k = lot location

e_i = percent error at station i

HYLD$_i$ (ASSIGNED) = the average yiebd figure developed from historic data.

n = number of inspection stations

The total possible error in the number of units expected to finish from all stations is:

$$\Delta \text{ ALL} = \sum_{k=1}^{n} X_k \prod_{i=k}^{n} (\text{HYLD}_i(\text{ASSIGNED}) + e_i) \sum_{i=k}^{n} e_i(\%)$$

where

Δ ALL = the difference between the true and calculated value of units expected to finish from all stations

k = lot location

X = units at location k

n = total number of locations

e_i = percent error at station i

HYLD$_i$ - the average yield figure developed from historic data.

The number of units short is developed from the following equation:

SHORT = REQ - INV - FINISH

where FINISH is equal to:

$$\sum_{k=1}^{n} X_k \prod_{i=k}^{n} (HYLD_i(ASSIGNED) + e_i)$$

and

SHORT = number of units the system is deficient in meeting demand

REQ = demand

INV = inventory

FINISH = number of units expected to finish.

REQ and INV are constants; thus the error in the term SHORT is a direct function of the error in the term FINISH. Symbolically this is represented as follows:

$$\Delta \text{ SHORT} = \Delta \text{ALL} = \sum_{k=1}^{n} X_k \prod_{k=1}^{n} (HYLD_i(ASSIGNED) + e_i) \sum_{i=k}^{n} e_i$$

where

Δ SHORT = difference between the true and calculated number of units the system is expected to be deficient of requirements.

Δ ALL = the difference between the true and calculated value of the units expected to finish.

The number of additional units to start is developed from the following equation;

NEW START = SHORT/OVERALL YIELD

The percentage error in the number of new starts is equal to the sum of the percentage errors in SHORT and the OVERALL YIELD. The error for SHORT has already been developed, and the error attributable to the OVERALL YIELD is very similar to the error in the units expected to finish. The error attributable to the yield is:

$$\text{SHORT} \prod_{e=1}^{n} (\text{HYLD}_i(\text{ASSIGNED})+e_i) \sum_{e=1}^{n} e_i(\%)$$

Thus the total possible error in the signal as to how many additional units to start is:

$$\Delta\text{NEW START} = \sum_{k=1}^{n} X_k \prod_{i=k}^{n} (\text{HYLD}_i(\text{ASSIGNED})+e_i) \sum_{i=k}^{n} e_i +$$

$$\text{SHORT(TRUE)} \prod_{e=1}^{n} (\text{HYLD}_i(\text{ASSIGNED})+e_i) \sum_{e=1}^{n} e_i(\%)$$

or since

$$\text{SHORT(TRUE)} = \sum_{k=1}^{n} X_k \prod_{i=k}^{n} (\text{HYLD}_i(\text{ASSIGNED})+e_i)$$

$$\Delta \text{ NEW START} = \sum_{k=1}^{n} X_k \prod_{i=k}^{n} (\text{HYLD}_i(\text{ASSIGNED} + e_i)$$

$$-\left[\sum_{i=k}^{n} e_i + \sum_{e=i}^{n} e_i \prod_{i=k}^{n} (\text{HYLD}_i(\text{ASSIGNED}) \quad e_i) \right]$$

The magnitude of this error in the signal is of course dependent upon the magnitude of the errors in the several yields, but it is also dependent upon any bias found in the assigned yield figures. If there is no bias in the selection of these figures, (that is, if the data from which they are developed is representative of the normal state of the production process), then the errors will tend to cancel. The reason for this is that as more data is collected, the mean assigned yield will tend to approach the true yield. Since there is no bias in the data it is just as likely that the assigned mean yield will approach the true yield from above as below. Relating this to the calculations for percentage error, we see that when the value approaches from above, the error is negative, and when it approaches from below, the error is positive. Consequently, when the summation is taken, there will be a cancellation effect operating on the errors. On the other hand, if the data is biased, and all errors fall to one side, then significant deviations from the correct signal can occur.

To illustrate the magnitude of these possible error effects consider the following illustration where there is no inventory and the requirements are for 1500 units in the next three weeks, 500 per week. The yields and units in process for a cycle with three inspection stations are as given below:

STAGE	YIELD			e(%)	UNITS
	ASSIGNED	TRUE	Δ		
1	.75	.70	-.05	-7.1%	1000
2	.80	.75	-.05	-6.67%	500
3	.80	.85	+.05	+5.9%	500
OVERALL	.48	.446			

From this we develop the number of units expected to finish:

$$\text{FINISH} = \sum_{k=1}^{n} X_k \sum_{i=k}^{n} \text{HYLD}_i(\text{ASSIGNED}/\text{TRUE})$$

the number of units short:

$$\text{SHORT} = \text{REQ} - \text{INV} - \text{FINISH}$$

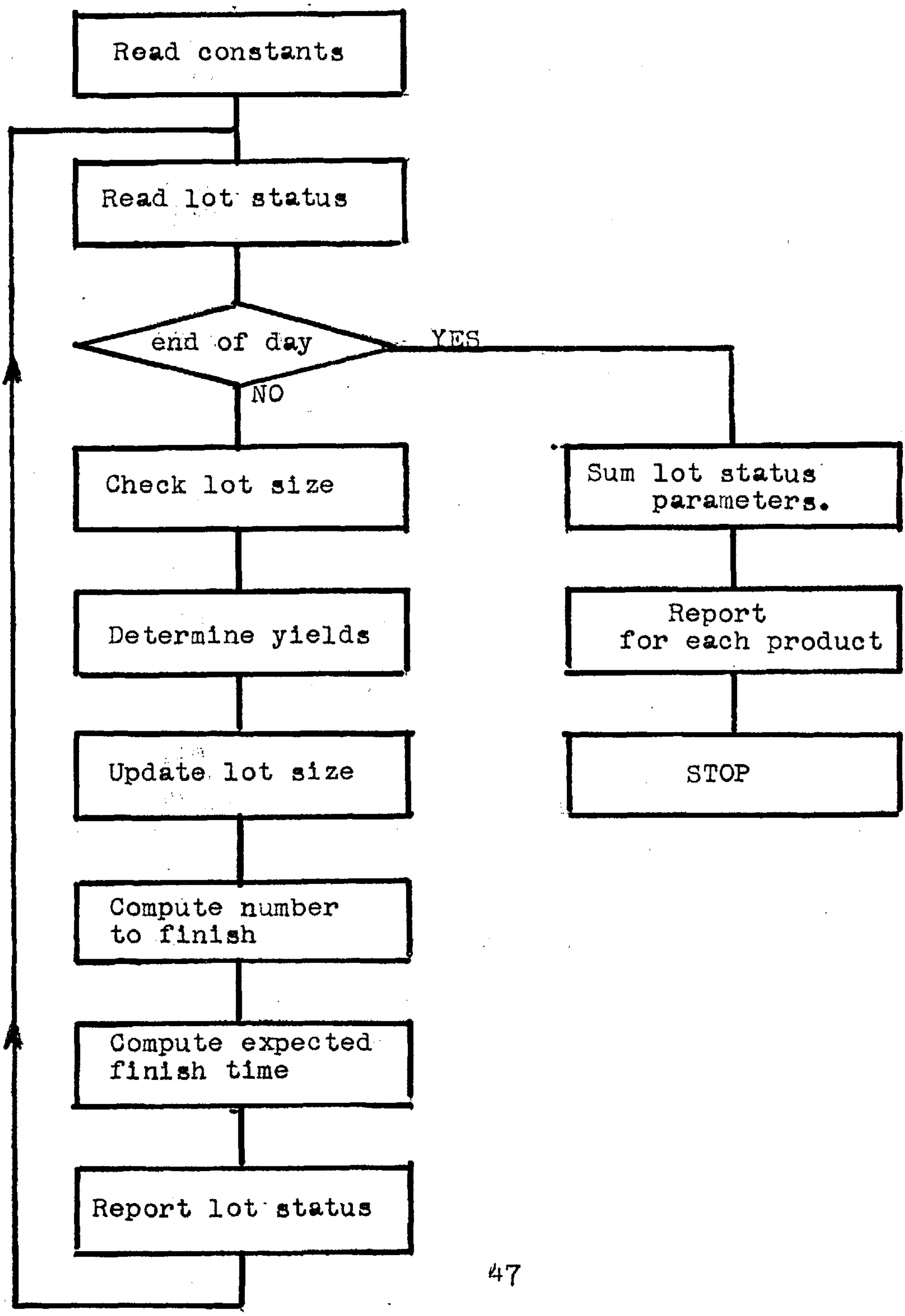
and the number ofadditional starts:

$$\text{START} = \text{SHORT} / \sum_{i=1}^{n} \text{HYLD}_i(\text{ASSIGNED}/\text{TRUE})$$

YIELD	ASSIGNED	TRUE
FINISH	1200	1190
SHORT	300	310
NEW START	625	695

The difference between the number of units to start under perfect information and under the data developed information is 70 units or about 10%. The system would thus seem to be very sensitive in this regard. To insure accurate results the main effort in implementing the system should be put in obtaining good estimates of the true system yields. This can only be done by collecting a large amount of data.

PROGRAM FLOW CHART, MACRO



PROGRAM DESCRIPTION

The program to implement the system is presented in Appendix I. A description of the program can be broken down into four sections, the inputs, the operations, the summations, and the output.

The initial loop labeled 20 zeros the matrices so that extraneous values are not present when the summations are taken. This is necessary because most of the matrix positions are not filled and may have leftover values in the locations. The next four cards set the size of the system. KK is the number of products to be considered, and N is the number of information points in the system. Having set the system dimensions, the input cards are read; the first set are system constants. PTIME is the expected time in days for a lot to pass from a given quality control point to finished good inventory. There is a PTIME for each product at each station. HYLD is the average yield of each quality control station for each product. This is used in the summation process to develop the units expected to finish and the number of additional units to begin. The second set of input cards describe the status of the production facility. REQ is the number of units required in a set time period (in this case, 3 weeks). INV is the inventory on hand. MINUS is the withdrawals from inventory. XX as the number of units at the last reported quality station. It is used to insure that no units are lost.

The last input set is the data for the units in process, X. These cards detail the product type, lot number, lot position, units in the lot, units accepted, sent for rework, and rejected from the quality control sample, and the number scrapped by production. The X cards are read in and processed singlely. Having read in the inputs, the program now proceeds with the computation.

The body of the program performs several tests and operations on the units in process, X, cards. As a first step, the program tests is determine if the number reported in process today is within 1% of the number last reported, XX. The 1% deviation was allowed due to the large number of units and their small size, which many times results in a few lost or miscounted pieces. If there is a significant difference in unit count, a message is printed and the last reported amount taken to be the true value. The report contains the following information:

(1) the station and lot number

(2) difference in unit count between the position where the lot was last reported and its position now.

(3) the percentage difference.

The next step is to determine if the lot has passed through the quality control point. At this point there is a branch for lots which have reached the last inspection station (100% inspection). The policy here is to fail the lot if it has any units for rework. If there are no units for rework, the units judged to be of good quality are added to passive inventory. The program then reads another unit card. On the other hand, if the lot is at an intermediate station, the yield is determined from the following formula:

$$\text{YIELD} = \text{ACCEPTED}/(\text{ACCEPTED}+\text{REWORK}+\text{REJECT})$$

If a lot fails inspection, a check digit is set, the number of scrapped units deducted, and a message is printed that the lot has failed. The failed lot statement lists the following:

(1) station and lot number

(2) lot size

(3) sample size

(4) units accepted in the sample

(5) units sent for repair in the sample

(6) units scrapped in the sample

(7) units scrapped from production

(8) sample yield

The program then jumps to the routine where the number of units expected to finish is computed. This is done to present an undistorted picture of the number of units expected to finish. If the sum of the units expected to finishwere derived only from lots which passed the inspection station, the report would have a low bias, tending to call for more additional starts than necessary.

On the other hand, if the lot passes, the program moves directly to compute the number expected to finish. This number is determined by multiplying the units in the lot times the average yield to passive inventory. Still computing for the accepted lot, the program next moves to compute the expected finish time. The date is translated into the day of the year to which is added the expected production time in days until completion, which is then translated back into expected finish date. These estimates are given in one half day intervals, for any finer values, would be more guess than estimate. The final step in this section is to print out the lot status, given that it has passed inspection.

Having computed the required information, the program prints a report of the status of the accepted lot. The following information is given on the report:

(1) lot number and location

(2) lot size

(3) sample size

(4) units accepted

(5) units scrapped

(6) units for rework

(7) yield

(8) average yield for that product at that station

(9) units expected to finish

(10) expected finish time

The program now returns to statement 180 to read another lot status card. Upon completion of all the cards for inprocess lots the program jumps to the summation section. This jump is signalled by a final control card with a 1 in column 80.

The third section carries out summations of the status of the inprocess units, done along product types. The particular records which are summed are:

(1) number of units scrapped by production

(2) number of units expected to finish

(3) overall yield

(4) number of units in process

(5) number of units rejected in QC sample

(6) number of units sent for rework

These summations are used in part for the product report, and in part to compute the number of additional units to start.

Upon completion of the summations for a particular product the program then proceeds to compute the number of additional units to start. The sequence of operations is as follows: The deductions from inventory are noted and the requirements to the active line adjusted. The number of units short is then developed from which the number of units to start is determined. However if the additional starts are negative, the program sets STRT(K). From these computations and the summations the product report is printed. This report lists the following items:

(1) product type

(2) additional units which should be started to meet active's requirements

(3) total of units scrapped today, both in production and sampling

(4) total number of units in process

(5) inventory on hand

(6) total number of units for rework

(7) sum of units expected to finish

In its final steps the program punches updated inventory, updated requirements, and updated lot position cards to be used as input for the next run. Additionally, as an aid to see more clearly the status of the inprocess circuits, the matrix of the lot cards is punched. This matrix of dimensions lot number by quality control station, shows the position and number of units at each point. Finally, the record of the lot progress is punched, to illustrate the progress the lot has made. On this matrix again dimensioned lot number by quality control station, the number of units at each of the quality control points is recorded. This presents a clear picture of the lot's progress through the cycle.

SYSTEM OPERATION

RESULTS

Since this system is not currently in operation, a true validation of it is not possible. However, an attempt has been made to simulate the conditions existing within the production process. Data was collected over a three week period for three product types. To reduce the number of computer runs required to process this data, the inputs were divided into eight groups. On each of the first three days (or computer runs) a lot was started for each product type. On the fourth and fifth days additional lots were begun for one product which was sustaining some particularly poor yields. This action was to illustrate the ability of the system to adapt to production faults. Production time was taken to be five simulated days which allowed for all lots to finish by the eighth day. In this manner the system started itself up, attained a high level of production, and then ran itself out of work.

The system constants were developed from discussions with the production management and a review of the data available. The PTIME values were obtained from the production management and or given in one half day intervals. The values for HYLD were derived from a month's data on the yields of the several inspection stations. REQ was set at 1800 units for the period. This value was chosen for the demand for passive circuits is approximately 600 units per week, MINUS, inventory withdrawals, was set to zero in order to obtain a clearer picture of the system operation. The output is represented graphically to clearly illustrate the functioning of the system.

Graph I is a plot of the number of units in process on any of the eight days, the number of units in process builds up rapidly as new lots are begun each day. On day three the last lot is started and from then on the units in process fall. During days four and five the decline is not as severe as in six and seven. The reason for this is that during days four and five the reduction in the number of units in process is due solely to the units being scrapped. However, on days six and seven lots are also moving into inventory, thus causing sharp declines in the number im process. It should be noted that there is a split in the plot for product V. The lower line represents the number of units in process if no additional lots are begun. The upper line represents the number in process if additional lots are begun to take up the slack caused by the poor yields on the first three. Clearly the lower plot falls off much more rapidly than the other three since for product V, scrapped units increases quickly.

Graph II indicated the number of units scrapped on a time basis. Here the reason for the low units in process line for product V becomes apparent. The units of V scrapped shoots far above those for the other products. As before the split in the V line represents the two cases, no additional starts and two additional lots. The segment for the additional lot case rises above the first case because with two more lots inprocess, there are more units being scrapped. The curves form a gentle S shape for two reasons. At the initial stages inspection and consequent rejection of units in their first production phases is limited. At the end the falling of of units scrapped, is the result of having fewer units in process (ie..lots have been added to inventory). The mid portion reveals the combination of many units inprocess plus closer inspection of the units. As a control device a plot over time of the units scrapped at the several locations can be maintained to point up weak points in the cycle.

Graph III points up more clearly the ability of the system to signal additional starts. There are two related plots on this graph; the first is the number of units expected to finish and the second is the number of additional starts. The horizontal line represents the system requirements. It should be noted that as long as the number of units expected to finish is less than the requirements, there will be a signal for additional starts. This is seen in the initial runs where all three products fall below the line and additional starts are high. However, as more lots are started, the expected finishes rise quickly and the additional starts fall quickly.

Again the plight of product V becomes apparent. Exhibiting poor yields all along, on days four and five disaster strikes; the units now expected to finish are far short of the requirements and new starts begin to climb rather than fall. With no additional lots the results are clear; not enough units reach inventory and the new start line remains high. On the other hand, if the signnals are heeded and more lots are begun, the poor results can be smoothed. This is demonstrated in the second set of product V lines which show a fourth lot being started on day three. The expected finish line shows a strong movement upward with a corresponding decrease in new starts. Yet new starts stand at 350 units, and as insurance against further faults, a fifth lot is begun on day four. Now product V appears in satisfactory condition for more units are expected to finish than are required. The only consideration now is to expedite the fifth lot to insure that it reaches inventory on time.

Graph IV shows the accumulation of inventory as lots come off the cycle into inventory. For products R and T the accumulation is satisfactory and they attain sufficient inventory to meet demand. However, product V shows its poor yields by accepting only a few units into inventory. The lower line again represents the non additional start case while the upper line represents the case for starting additional units.

The overall picture is seen best in Graph V where new starts, expected finishes, units in process, and inventory are plotted together for product V. The two sets of lines show the clear contrast involved in abiding by and not abiding by the new start signal. Though these results are only a simulation of the actual system, they do demonstrate the ability of the system to issue corrective signals to smooth production faults and meet demand.

KEY TO GRAPHS

Product R

Product T

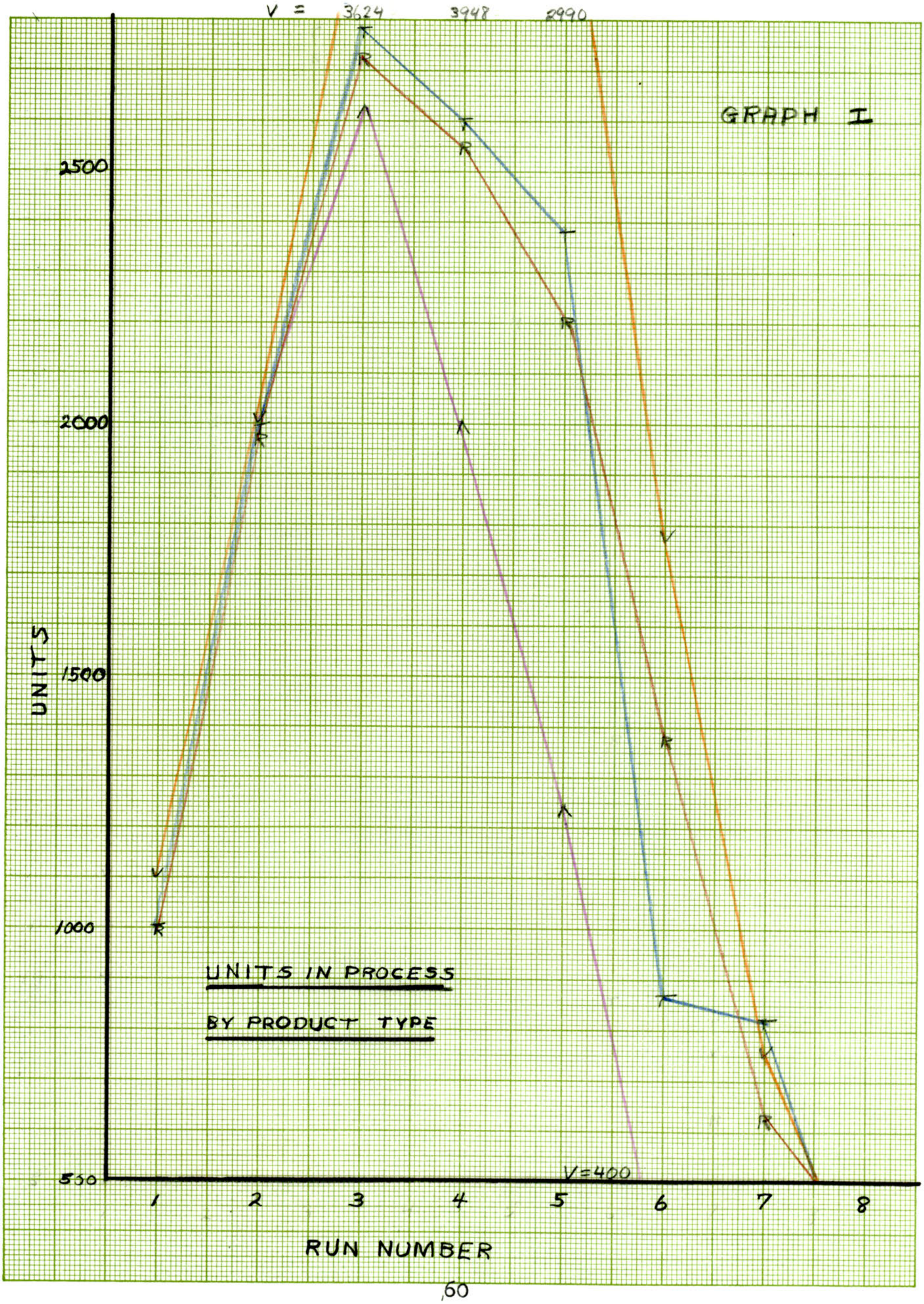
Product V - using additional lots

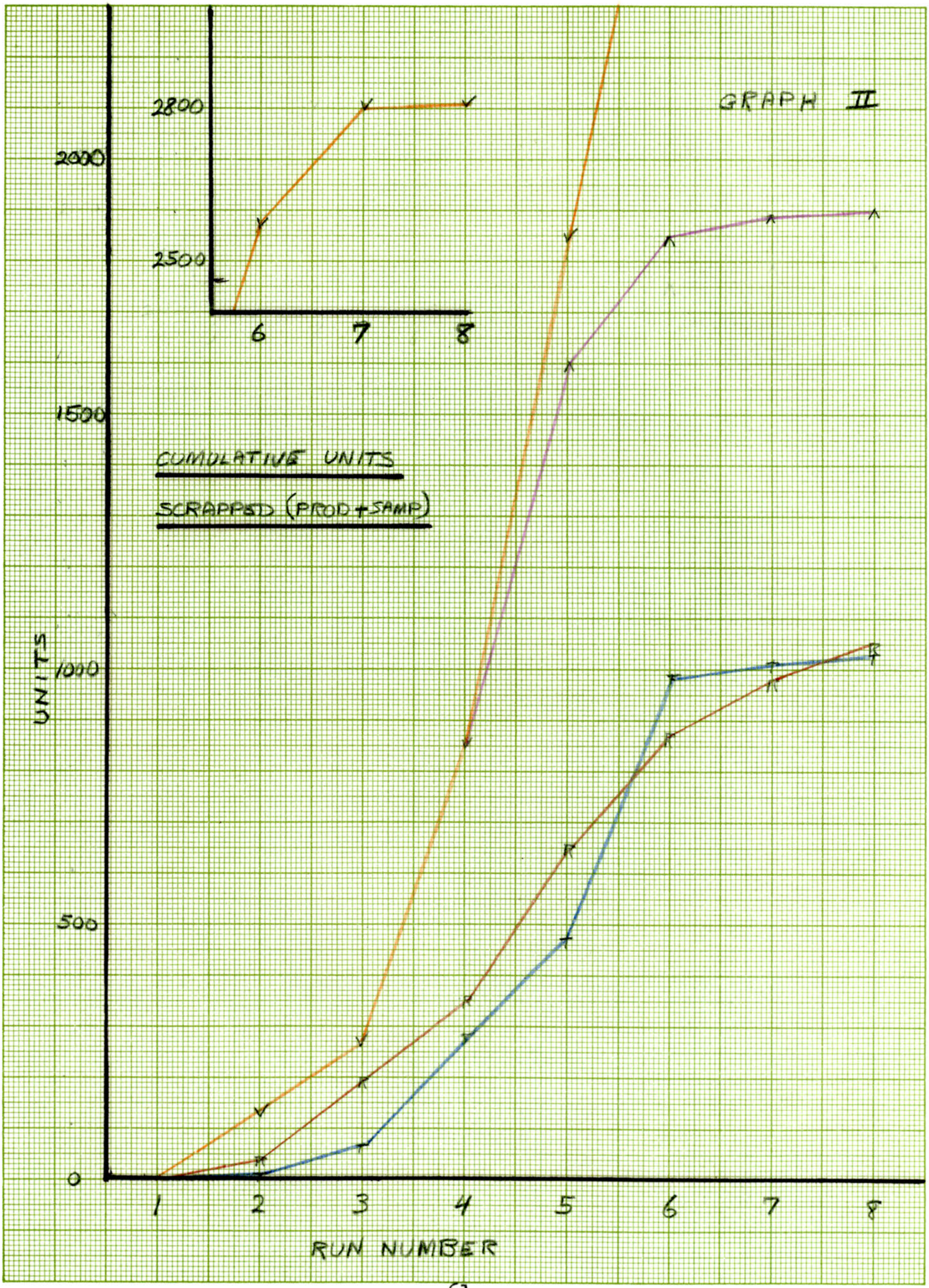
Product V - using no additional lots

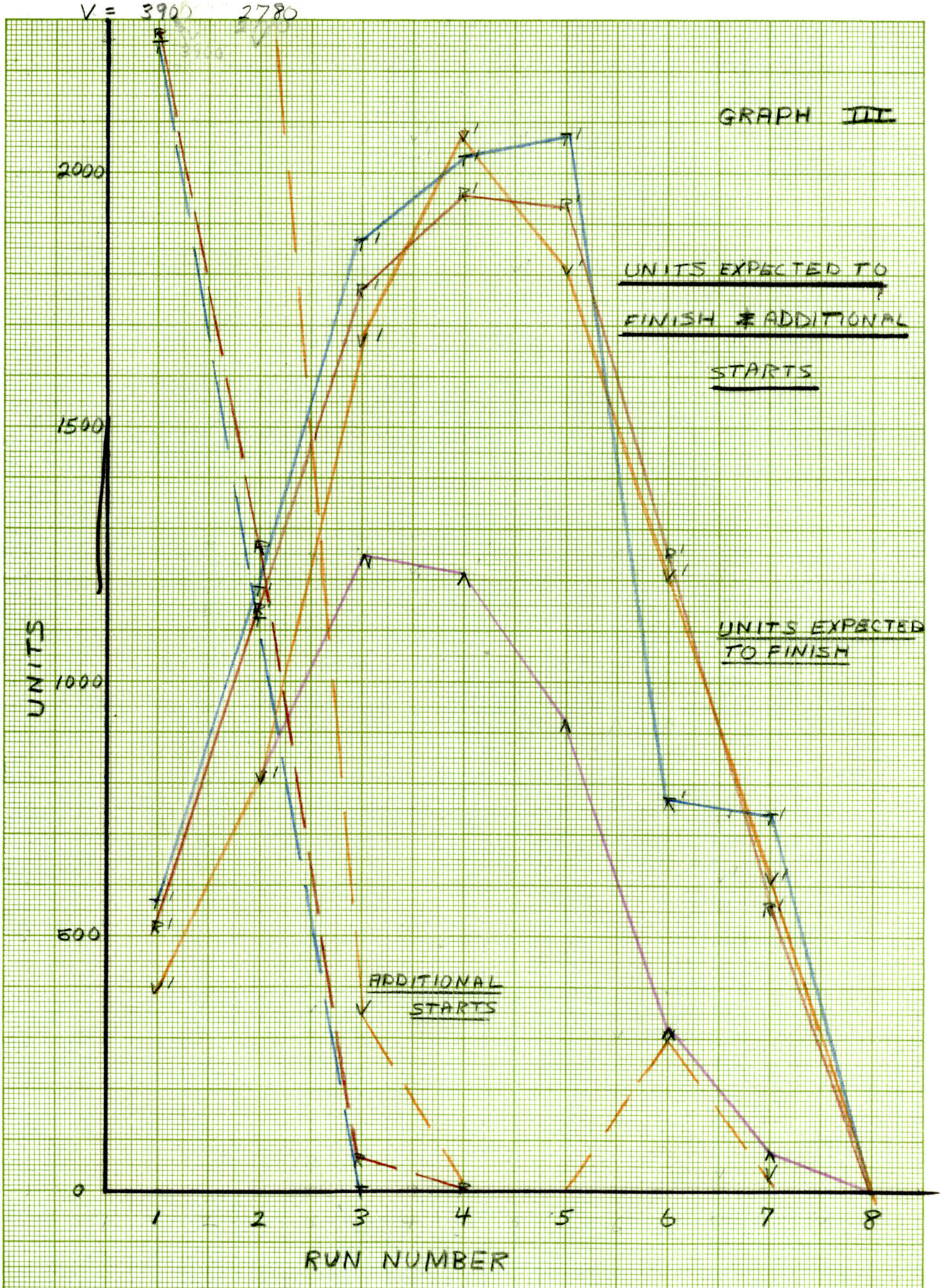
Additional starts - Product R

Additional starts - Product T

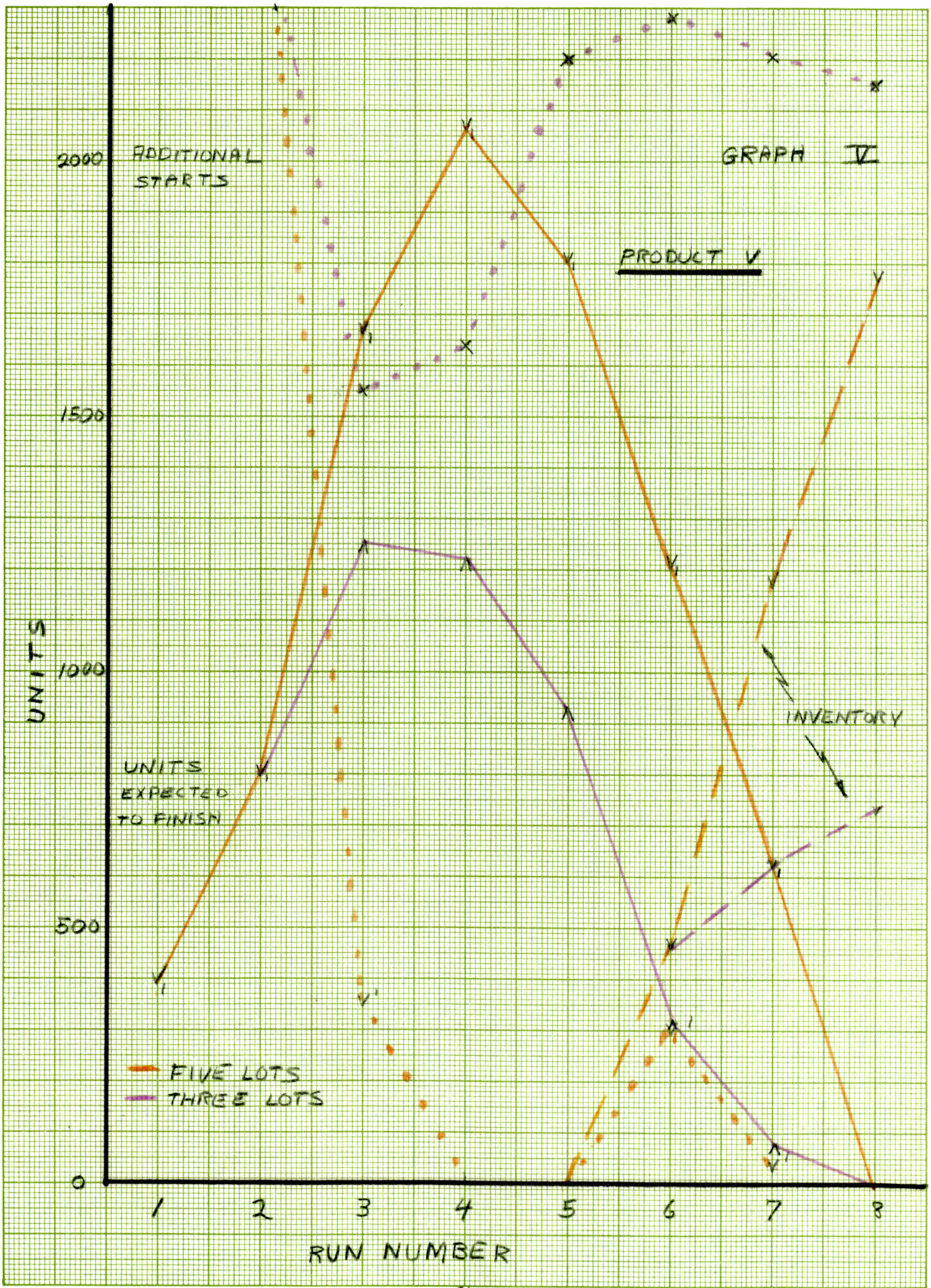
Additional starts - Product V - when extra lots are started


V = 3624 3948 2990
GRAPH I
2500
2000
1500
1000
500
UNITS
UNITS IN PROCESS
BY PRODUCT TYPE
V=400
1 2 3 4 5 6 7 8
RUN NUMBER


GRAPH II
CUMULATIVE UNITS
SCRAPPED (PROD + SAMP)
UNITS
RUN NUMBER
0
500
1000
1500
2000
1
2
3
4
5
6
7
8
2500
2800
6
7
8


V = 3900 2780
GRAPH III
2000
1500
1000
500
0
UNITS
UNITS EXPECTED TO FINISH & ADDITIONAL STARTS
UNITS EXPECTED TO FINISH
ADDITIONAL STARTS
1
2
3
4
5
6
7
8
RUN NUMBER

GRAPH IV
INVENTORY BY PRODUCT TYPE
SYSTEM REQUIREMENTS
UNITS
2000
1500
1000
500
0
1
2
3
4
5
6
7
8
RUN NUMBER



GRAPH V
PRODUCT V
ADDITIONAL STARTS
UNITS EXPECTED TO FINISH
INVENTORY
FIVE LOTS
THREE LOTS
UNITS
RUN NUMBER
2000
1500
1000
500
0
1
2
3
4
5
6
7
8

IMPLEMENTATION

The implementation of this information system can be accomplished with little adaptation of the present production cycle. The data is currently being collected, the computer is available, and all that need be done is to establish procedures for the operation of the system.

The quality control department collects the required data for their work in quality assurance. The information they maintain is listed below:

(1) Number of units at each Q.C. station

(2) Results of the Q.C. sample

- (a) Number accepted
- (b) Number rejected
- (c) Number sent for rework
- (d) Rejectance or acceptance of lot

There are four quality sampling points in the cycle and a final 100% quality check at the end of the process. These stations will make ideal points for information gathering. Their obvious benefits are: (1) presently established information gathering procedures and locations, (2) collection of the necessary in process data, (3) an adequate number of stations to obtain sufficient information to control the process. In addition to the information gathered at these stations, the following information must be obtained:

(1) The schedule of deliveries

(2) The inventory on hand

(3) Withdrawals from inventory

It is a simple step from having sufficient data to putting it in usable form.

The data will be collected in the latter part of the day, and recorded on sheets, which will be set up in the format of the input cards. An example of this sheet is given on page . From this sheet the data cards will be punched. It is expected that there will be no more than 20 cards to be punched on a given day. Once the cards have been punched, they will be sorted, added to the program object deck and run on the computer. The output will thus be applicable to the status of the cycle of the day just posted and will be available for use by management on the next morning. The report will give them the information required to make the decision as to how many additional units must be started. The results of the computer run can also be plotted to establish the trends for the improvement of the production process (the secondary use of the system). Thirdly, the system will provide timely reports on the status of the production process.

Initially this system should be implemented in parallel to the existing information system. In this manner

DATA SHEET

						CARD COLUMN
DATE						
PRODUCT						3
STATION	1	2	3	4	5	9
LOT NO.						6
UNITS						10-17
SAMPLING RESULTS						
NO. IN SAMPLE						
ACCEPTED						18-25
REWORKS						26-33
REJECTS						34-41
PRODUCTION						
SCRAPPED						42-49
NEW LOTS						
LOT NO.						6
SIZE		X	X	X	X	10-17

the proposed system can be evaluated against the current system, and any necessary adjustments can be made to bring performance up to desired levels. Once the bugs have been eliminated, the system can be put in full operational use.

SUMMARY

The benefits that will be derived from the implementation of this system can be broken into two segments, better planning of the production cycle and better control over the production cycle. The planning advantage arises from the capability of the system to forecast the number of units to introduce into the cycle to satisfy demand. The control portion is enhanced by the ability of the system to keep a record of the movements of all the in process goods.

In the framework of this information system, planning takes on a limited role in the scheduling area. The signal given by this system is of a short term nature, only a week or two. Yet this length of time is sufficient to permit the more effective use of the production facilities through an orderly scheduling procedure. With knowledge of the number of units in process, their expected finish time, and the number expected to finish, much of the guesswork will be taken out of scheduling. Using this system the operation manager will have available all the information he needs to make the correct decision, both in terms of which product to concentrate on and an estimate of how many units to begin.

The control function is enhanced for many of the same reasons; using this system there will be more information available with which one can make decisions by. This information will be presented in a concise form thus further facilitating its use. Secondly, the program contains a routine which keeps track of discrepancies in the reported number of units in process, this improving control. In essence, the control function is centered more about information organization than reactive signals; it presents the information which the production staff can utilize to control the process.

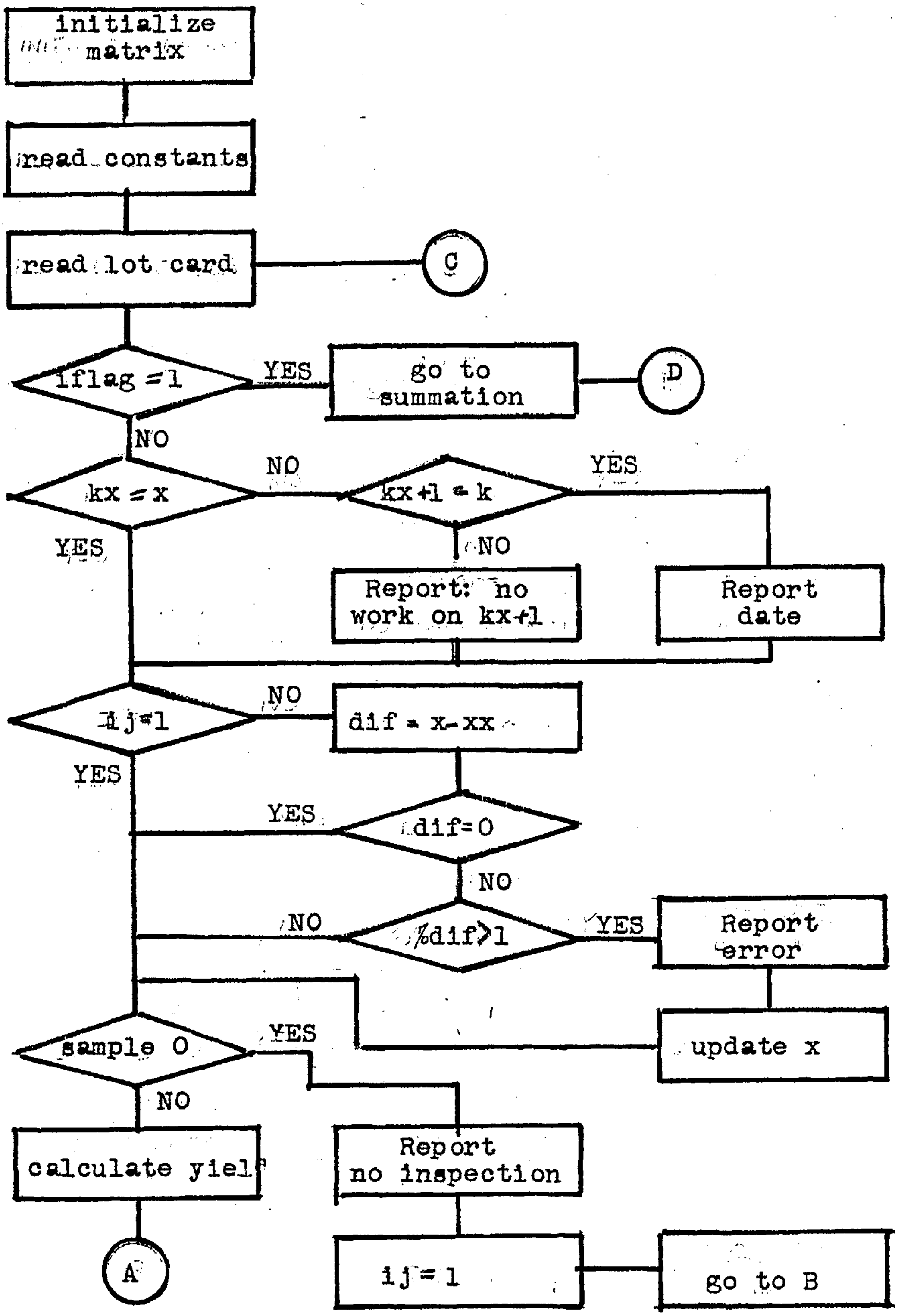
FUTURE STUDY

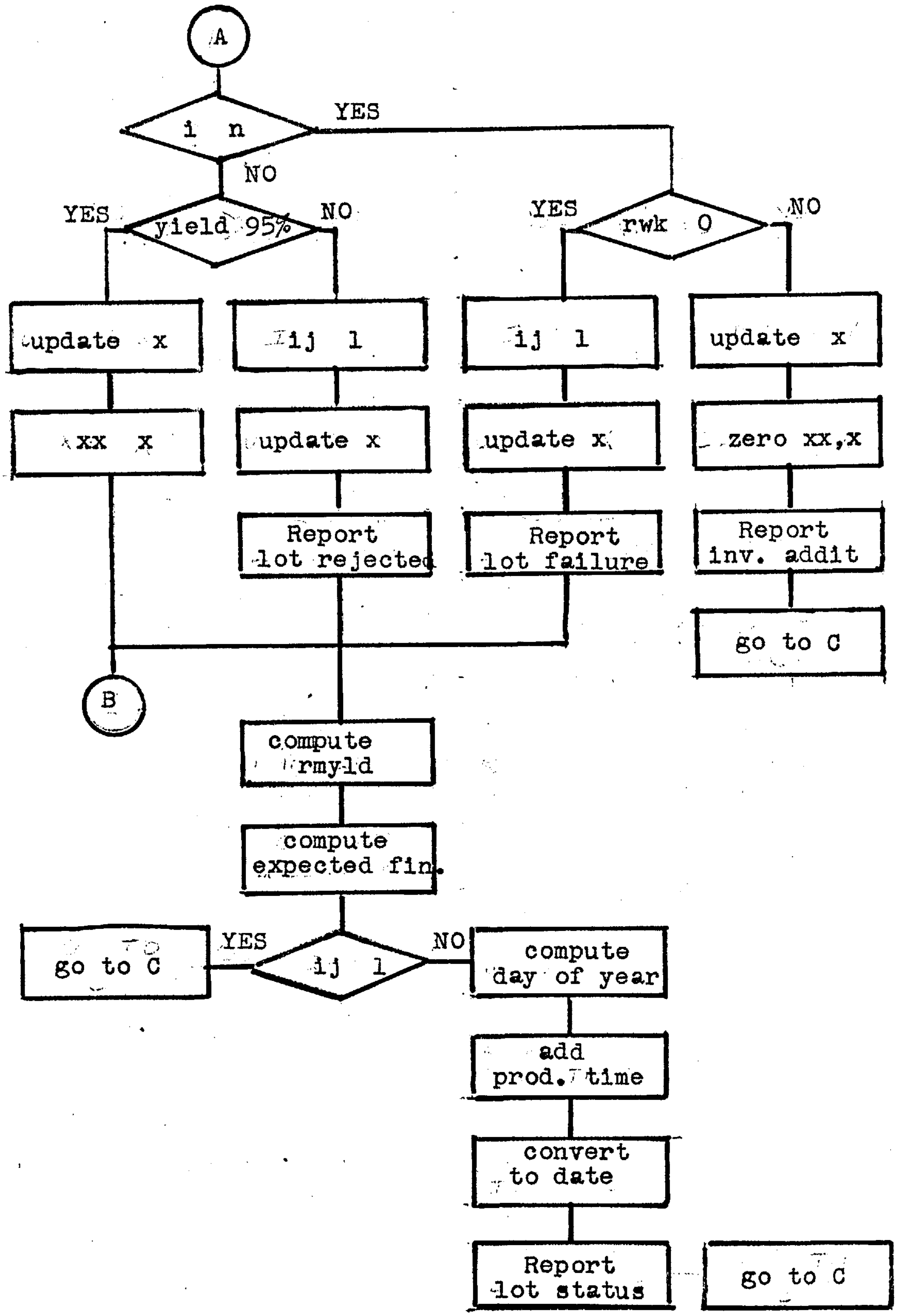
The system presented in this thesis is an initial step in the development of a complete system for production planning and control. The next step in its development of the system could be the addition of a subroutine to monitor and modify the system constants to achieve more accurate results. Following this another step would seem to be establishing a similar system for the active portion of the process. Then these two systems could be tied together to form one system for the entire production process. Following this a system could be developed to issue the weekly quality control reports. This system would use as inputs the product in process cards for the entire week. Finally an inventory control system could be developed to control the inventory. This would have as its inputs the activity level in the production process (i.e.,parts required).

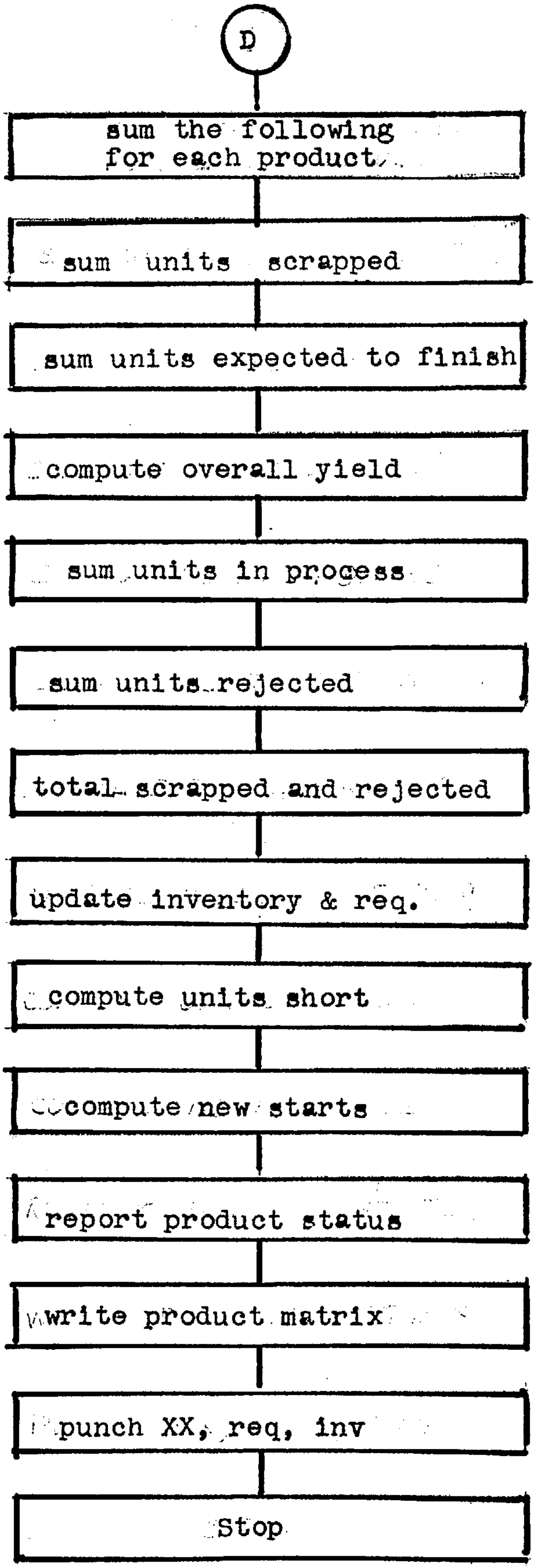
APPENDIXES

APPENDIX I

SYSTEM FLOW DIAGRAM




A
i n
YES
NO
yield 95%
YES
NO
rwk 0
YES
NO
update x
xx x
ij 1
update x
Report
lot rejected
ij 1
update x
Report
lot failure
update x
zero xx,x
Report
inv. addit
go to C
B
compute
rmyld
compute
expected fin.
go to C
YES
ij 1
NO
compute
day of year
add
prod. time
convert
to date
Report
lot status
go to C


D
sum the following for each product.
sum units scrapped
sum units expected to finish
compute overall yield
sum units in process
sum units rejected
total scrapped and rejected
update inventory & req.
compute units short
compute new starts
report product status
write product matrix
punch XX, req, inv
Stop

APPENDIX II

SYSTEM PRØGRAM

```
C    PTIME = PRØDUCTIØN TIME FRØM STATIØN TØ INVENTØRY
C    HYLD = HISTØRIC AVERAGE YIELD
C    TTYLD = TØTAL YIELD
C    RMYLD  = TØTAL REMAINING YIELD
C    ACYLD = ACTUAL YIELD
C    INV = INVENTØRY
C    MINUS = UNITS TAKEN FRØM INVENTØRY
C    REQ = REQUIREMENTS FØR TIME PERIØD
C    X = UNITS IN A LØT
C    ACP = UNITS ACCEPTED IN SAMPLE
C    SCR = UNITS SCRAPPED BY PRØDUCTIØN
C    RJT = UNITS REJECTED IN SAMPLE
C    RWK = UNITS SENT FØR REWØRK
C    XX = LAST REPØRTED NØ. ØF UNITS IN LØT
C    SMRJT = SUM ØF UNITS REJECTED
C    ACCP = SUM ØF UNITS ACCEPTED INTØ INVENTØRY
C    SUMFN = SUM ØF UNITS EXPECTED TØ FINISH
C    SUMX = SUM ØF UNITS IN PRØCESS
C    FNLX = UNITS EXPECTED TØ FINISH FRØM A PARTICULAR LØT
C    SSCR = SUM ØF UNITS SCRAPPED BY PRØDUCTIØN
C    RRWK = SUM ØF UNITS FØR REWØRK
C NFIN = EXPECTED FINISH DATE FØR A LØT
      INTEGER Z(3,10,6)
      INTEGER     MINUS(3), FNLX(3,10,6),INV(3),SCR(3,10,6),SSCR(3)
      INTEGER RWK(3,10,6),  X(3,10,6),ACP(3,10,6),RJT(3,10,6),XX(3,10,6)
      +NTEGE- ST-TU3),--WKU3),SM-JTU3),SUMFNU34
      DIMENSIØN TTYLD(3),RMYLD(3),HYLD(3,6),PTIME(3,6),NFIN(3,10)
   10 DØ 20 K = 1,3
      INV(K) = 0
      REQ(K) = 0
```

```
      MINUS (K) = 0
      DØ 20 J = 1,10
      DØ 20 I = 1,6
      Z(K,J,I) = 0
      X (K,J,I ) = 0
      ACP ( K,J,I ) = 0
      RJT (K,J,I ) = 0
      XX(K,J,I) = 0
      RWK(K,J,I) = 0
      FNLX(K,J,I) = 0
      SCR (K,J,I) = 0
   20 CØNTINUE
      ISKIP = 1
      KK = 3
      N = 6
      KX = 0
      IF ( IFLAG - 2 ) 70,150,70
   70 READ (2,071) (N,(PTIME(K,I),I = 1,N),K = 1,3)
  071 FØRMAT (I5,6F10.2)
      READ (2,081) (N,(HYLD(K,I),I = 1,N),K = 1,3)
  081 FØRMAT (I5,6F10.2)
  150 READ (2,151) (REQ(K),K = 1,3)
  151 FØRMAT ( I10)
      READ ( 2,161 ) (INV (K) , K = 1,3 )
  161 FØRMAT ( I10 )
      READ ( 2,170 ) ( MINUS (K) , K = 1,3)
  170 FØRMAT ( I10 )
      READ (2 , 051 ) MT , NDAY
  051 FØRMAT(2I10)
      READ (2,121)(((XX(K,J,I),J=1,10),I=1,N),K=1,KK)
  121 FØRMAT (10I8)
C     INPUT ØF LØT IN PRØCESS CARDS. ØNE CARD PRØCESSED AT A TIME.
  180 READ(2,181) K,J,I,  X(K,J,I),ACP(K,J,I),RWK(K,J,I),RJT(K,J,I),
     1 SCR(K,J,I) , IFLAG
  181 FØRMAT ( 3I3 , 5I8 , 30X , I1 )
```

```
C    BRANCH TØ DETERMINE THE PRØDUCT TYPE. IF IFLAG = 1, ALL X(K,J,I) CARDS READ
        IF(IFLAG - 1)220,1940,220
  220 IF ( KX - K ) 230,260,260
  230 KXX = KX + 1
        IF ( KXX - K ) 245,250,245
  245 WRITE ( 3,246 ) KXX
  246 FØRMAT ( 25H NØ REPØRT FØR   PRØDUCT I3 )
  250 KX = K
      WRITE (3,241) ISKIP , MT , NDAY , K
  241 FØRMAT(I1,18H    DATE      MØNTH I3,7H    DAY I3//9H PRØDUCT I2//)
  260 IJ = 0
C    CHECK TØ DETERMINE IF THE NUMBER ØF UNITS LAST REPØRTED TALLIES WITH
C    THE NUMBER  CURRENTLY IN THE LØT
        IF ( I - 1 ) 261,261,262
  261 XX(K,J,I) = X(K,J,I)
      GØ TØ 275
  262 MM = I - 1
      IF( XX(K,J,MM)) 271,265,271
  265 MM = MM - 1
  271 DIF = X(K,J,I)-XX(K,J,MM)
      DDIF = ABS(DIF)
      IF (DDIF) 275,275,272
  272 PRCT = 100. * DDIF / FLØAT(X(K,J,I))
      IF(PRCT - 1.0)275,275,276
  276 WRITE (3,277) I,J,DIF,PRCT
  277 FØRMAT (9H STATIØN I2,8H    LØT I2/10X,6H ERRØR    /28H DIFFERENCE
     1 IN UNIT CØUNT = F6.0/25H PERCENTAGE DIFFERENCE = F6.2/)
  275 ISAM = ACP(K,J,I)+RJT(K,J,I)+RWK(K,J,I)
      IF(ISAM)998,998,420
  998 WRITE (3,999) I,J,I,X(K,J,I)
  999 FØRMAT(7H FIELD I2,8H    LØT I2//' LØT IS IN FIELD 'I2/
     1 ' UNITS IN LØT = ' I6//)
      IJ = 1
      IF ( I - 1 )410,460,410
  410 I = I - 1
      GØ TØ 460
```

```
  420 ACYLD=FLØAT(ACP(K,J,I))/FLØAT(ACP(K,J,I)+RJT(K,J,I)+RWK(K,J,I))
      IF (I - N) 205,210,205
  205 IF (ACYLD - .95)215,280,280
C     210 TØ 213 MØVES A LØT FRØM THE LAST INSPECTIØN STATIØN TØ INVENTØRY
  210 IF(RWK(K,J,I))290,211,290
  211 INV(K) = INV(K) + ACP(K,J,I)
      DØ 212 L = 1,N
      XX(K,J,L) = 0
  212 CØNTINUE
      X(K,J,N) = 0
      WRITE(3,213)I,J,ACP(K,J,I),INV(K)
  213 FØRMAT(' STATIØN 'I2,5X,' LØT 'I2//' UNITS ADDED TØ INVENTØRY = '
     1 I6/ ' INVENTØRY = ' I6//)
      GØ TØ 180
C     290 TØ 291 UPDATES AND REPØRTS A FAILED LØT AFTER 100 PRCT INSPECTIØN
C     IF IJ = 1, THEN THE LØT WILL NØT MØVE FØRWARD ØN THIS RØUND
  290 IJ = 1
      Z(K,J,I) = X(K,J,I)
      X(K,J,I) = X(K,J,I) - RJT(K,J,I) - SCR(K,J,I)
      M = I - 1
      XX(K,J,M) = X(K,J,I)
      WRITE(3,291)I,J,Z(K,J,I),ACP(K,J,I),RWK(K,J,I),RJT(K,J,I),
     1 SCR(K,J,I)
  291 FØRMAT( ' STATIØN ' I2,5X, ' LØT ' I2//' LØT RETURNED TØ PRØDUCTIØ
     1N AFTER 100 PERCENT INSPECTIØN '/' UNITS IN LØT = 'I6/
     2 ' UNITS ACCEPTED = 'I6/ ' UNITS FØR REWØRK = ' I6 /
     3   ' UNITS REJECTED(SAM) = 'I6/' UNITS SCRAPPED(PRØD) = 'I6//)
      GØ TØ 520
C     215 TØ 201 UPDATES AND REPØRTS A FAILED LØT AFTER SAMPLING INSPECTIØN
  215 IJ = 1
      Z(K,J,I) = X(K,J,I)
      X(K,J,I) = X(K,J,I) - RJT(K,J,I) - SCR(K,J,I)
      M = I - 1
      XX(K,J,M) = X(K,J,I)
      WRITE(3,201) I,J,Z(K,J,I),ISAM,ACP(K,J,I),RWK(K,J,I),RJT(K,J,I),
     1 SCR(K,J,I) ,ACYLD
```

```
  201 FØRMAT (9H STATIØN I2,5H LØT I2//39H LØT HAS BEEN REJECTED AT 4 PE
     1RCENT AQL/12H LØT SIZE = I5//5H SAMPLE SIZE = I4/18H UNITS ACCEPTE
     2D = I5/20H UNITS FØR REPAIR = I5/26H UNITS SCRAPPED(SAMPLE) = I5/
     3 30H UNITS SCRAPPED(PRØLUCTIØN) = I5/ 9H YIELD = F4.2/)
      GØ TØ 460
  280 Z(K,J,I) = X(K,J,I)
      X(K,J,I) = X(K,J,I) - RJT(K,J,I) - SCR(K,J,I)
      XX(K,J,I) = X(K,J,I)
  460 IF (I - N )470,520,520
C   470 TØ 540 CØMPUTE THE NUMBER ØF UNITS EXPECTED TØ FINISH
  470 RMYLD(K) = 1.0
      M = I + 1
      DØ 51C L = M,N,1
      RMYLD(K) = RMYLD(K) * HYLD(K,L)
  510 CØNTINUE
      CØ TØ 540
  520 RMYLD(K) = HYLD(K,I)
  540 ENLX(K,J,I) = RMYLD(K) * FLØAT(X(K,J,I))
      IF (IJ - 1)810,180,180
  810 IF (ISAM)180,180,820
C   810 TØ 1110 TRANSLATE THE DATE INTØ THE DAY ØF THE YEAR
  820 IF (MT - 6 )850,830,900
  830 NDØY = 151 + NDAY
      CØ TØ 1110
  850 IF (MT - 4 )950,860,880
  860 NDØY =  90 + NDAY
      GØ TØ 1110
  880 NLØY = 120 + NDAY
      GØ TØ 1110
  900 IF ( MT - 8)930,910,1020
  910 NDØY = 212 + NDAY
      GØ TØ 1110
  930 NDØY = 181 + NDAY
      GØ TØ 1110
  950 IF ( MT - 2 )960,980,1000
  960 NDØY = NDAY
```

```
      GØ TØ 1110
  980 NDØY =  31 + NDAY
      GØ TØ 1110
 1000 NDØY =  59 + NDAY
      GØ TØ 1110
 1020 IF ( MT - 10 )1C30,1050,1070
 1030 NDØY = 243 + NDAY
      GØ TØ 1110
 1050 NDØY = 273 +NDAY
      GØ TØ 1110
 1070 IF ( MT - 12 )1080,1100,1100
 1080 NDØY = 304 + NDAY
      GØ TØ 1110
 1100 NDØY = 333 + NDAY
 1110 CØNTINUE
      ITIME      = PTIME(K,I)
      IF(PTIME(K,I) - ITIME     )1111,1111,1112
 1111 HALF = 0.0
      GØ TØ 1120
 1112 HALF = .5
C   CALCULATIØN ØF THE EXPECTED FINISH TIME
 1120 NFIN(K,J) =              PTIME(K,I) + NDØY
C   1111 TØ 1910+2 TRANSLATE THE DAY ØF THE YEAR TØ DATE
      IF (  NFIN(K,J) - 152 )1170,1140,1470
 1140 MMT = 6
      NNDAY = 1
      GØ TØ 1910
 1170 IF (   NFIN(K,J) - 91 )1210,1180,1380
 1180 MMT = 4
      NNDAY = 1
      GØ TØ 1910
 1210 IF(   NFIN(K,J) - 32 )1250,1220,1280
 1220 MMT = 2
      NNDAY = 1
      GØ TØ 1910
 1250 MMT = 1
```

```
      NNDAY = NFIN(K,J)
      GØ TØ 1910
 1280 IF (   NFIN(K,J) - 60 )1290,1320,1350
 1290 MMT = 2
      NNDAY = NFIN(K,J) - 31
      GØ TØ 1910
 1320 MMT = 3
      NNDAY = 1
      GØ TØ 1910
 1350 MMT = 3
      NNDAY = NFIN(K,J) - 59
      GØ TØ 1910
 1380 IF (   NFIN(K,J) - 121 )1390,1410,1440
 1390 MMT = 4
      NNDAY = NFIN(K,J) - 90
      GØ TØ 1910
 1410 MMT = 5
      NNDAY = 1
      GØ TØ 1910
 1440 MMT = 5
      NNDAY = NFIN(K,J) - 120
      GØ TØ 1910
 1470 IF (   NFIN(K,J) - 213 )1510,1480,1610
 1480 MMT = 8
      NNDAY = 1
      GØ TØ 1910
 1510 IF (   NFIN(K,J) - 182 )1520,1550,1580
 1520 MMT = 6
      NNDAY = NFIN(K,J) - 151
      GØ TØ 1910
 1550 MMT = 7
      NNDAY = 1
      GØ TØ 1910
 1580 MMT = 7
      NNDAY = NFIN(K,J) - 181
      GØ TØ 1910
```

```
 1610 IF (   NFIN(K,J) - 274 )1650,1620,1750
 1620 MMT = 10
      NNDAY = 1
      GØ TØ 1910
 1650 IF (   NFIN(K,J) - 244 ) 1660,1690,1720
 1660 MMT = 8
      NNDAY = NFIN(K,J) - 212
      GØ TØ 1910
 1690 MMT = 9
      NNDAY = 1
      GØ TØ 1910
 1720 MMT = 9
      NNDAY = NFIN(K,J) - 243
      GØ TØ 1910
 1750 IF (   NFIN(K,J) - 335 )1790,1760,1890
 1760 MMT = 12
      NNDAY = 1
      GØ TØ 1910
 1790 IF (   NFIN(K,J) - 305 )1800,1830,1860
 1800 MMT = 10
      NNDAY = NFIN(K,J) - 273
      GØ TØ 1910
 1830 MMT = 11
      NNDAY = 1
      GØ TØ 1910
 1860 MMT = 11
      NNDAY = NFIN(K,J) - 304
      GØ TØ 1910
 1890 MMT = 12
      NNDAY = NFIN(K,J) - 334
 1910 CØNTINUE
      FNDAY = NNDAY
      FNDAY = FNDAY + HALF
      WRITE (3,1930)I,J,Z(K,J,I),ISAM,ACP(K,J,I),RJT(K,J,I),RWK(K,J,I),
     1 ACYLD,HYLD(K,I),FNLX(K,J,I),MMT,FNDAY
```

```
 1930 FØRMAT(9H STATIØN I2,8H     LØT I2 //
     1 27H LØT ACCEPTED AT 4 PRCT AQL / 12H LØT SIZE = I6/
     115H SAMPLE SIZE = I4/17H UNITS ACCEPTED =I6/17H UNITS SCRAPPED =I6
     2 /20H UNITS FØR REWØRK = I4/9H YIELD = F4.2/16H AVERAGE YIELD = F4
     3.2/28H UNITS EXPECTED TØ FINISH = I5/22H EXPECTED FINISH TIME I2,
     4 3H / F4.1//)
      GØ TØ 180
C     SUMMATIØN ØF PRØCESSING RESULTS
 1940 DØ 2010 K = 1,KP
      WRITE (3,1979) ISKIP
 1979 FØRMAT (I1)
      SSCR ( K ) = 0
      DØ 770 L = 1,N
      DØ 770 M = 1,10
      SSCR ( K ) = SSCR ( K ) + SCR (K,M,L )
  770 CØNTINUE
      SUMFN(K) = 0
      DØ 750 M = 1,N
      DØ 750 L = 1,10
      SUMFN(K) = SUMFN(K) + FNLX(K,L,M)
  750 CØNTINUE
      TTYLD(K) = 1.0
      DØ 630 L = 1,N
      TTYLD(K) = TTYLD(K) * HYLD(K,L)
  630 CØNTINUE
      SUMX(K) = 0
      DØ 730 L = 1,N
      DØ 730 M = 1,10
      SUMX(K) = SUMX(K) + X(K,M,L)
  730 CØNTINUE
      SMRJT(K) = 0
      DØ 790 L = 1,N
      DØ 790 M = 1,10
      SMRJT(K) = SMRJT(K) + RJT(K,M,L)
  790 CØNTINUE
```

```
      SMRJT (K) = SMRJT (K) + SSCR (K)
      RRWK(K) = 0
      DØ 760 L = 1,N
      DØ 760 M = 1,10
      RRWK(K) = RRWK(K) + RWK(K,M,L)
  760 CØNTINUE
C     UPDATE INVENTØRY AND REQUIREMENTS AND CØMPUTE THE NUMBER SHØRT
      REQ(K) = REQ(K) - MINUS(K)
      INV(K) = INV(K) - MINUS(K)
      DELTA(K) = REQ(K) - INV(K) - SUMFN(K)
      IF ( DELTA(K))645,640,640
  645 STRT (K) = 0
      GØ TØ 670
C     CØMPUTATIØN ØF THE NUMBER ØF ADDITIØNAL STARTS
  640 STRT(K) =  DELTA(K)     / TTYLD(K)
C     SUMMARY REPØRT FØR THE PRØDUCT
  670 WRITE (3,1970) K, STRT(K),SMRJT(K),SUMX(K),INV(K),RRWK(K),SUMFN(K)
 1970 FØRMAT (25H       PRØDUCT REPØRT K = I2//21H ADDITIØNAL STARTS = I5
     1 /28H UNITS SCRAPPED(SMP+PRØD) = I5/20H UNITS IN PRØCESS = I5/
     2 20H INVENTØRY ØN HAND = I5 /20H UNITS FØR REWØRK = I4/
     335H SUM ØF UNITS EXPECTED TØ FINISH = I6///)
      WRITE (3,1981) REQ(K) , K
 1981 FØRMAT (I10,' REQUIREMENTS  K = ' I2)
C     PUNCH ØUT ØF THE REVISED REQ.THE MATRIX ØF UNITS IN PRØCESS,
C     AND THE LØT PRØGRESS MATRIX
      WRITE (3,2004)
 2004 FØRMAT(' UNITS IN PRØCESS '/' RØWS ARE YIELD STATIØNS '/
     1 ' CØLUMNS ARE LØT NUMBERS '//)
      WRITE  (3,2005)  ((X(K,J,I),J=1,10),I=1,N)
 2005 FØRMAT (10I8)
      WRITE (3,2006)
 2006 FØRMAT ( 30X , 'XX'//)
      WRITE (3,2007) ((XX(K,J,I),J=1,10),I=1,N)
 2007 FØRMAT (10I8)
      WRITE (2,2040) REQ(K) , K
 2040 FØRMAT (I10,' REQUIREMENTS  K = ' I2)
```

```
      WRITE ( 2,2050 )  INV ( K ) , K
 2050 FØRMAT ( I10,28H           INVENTØRY FØR K = I2 )
      WRITE (2,2080) ((XX(K,J,I),J=1,10),I=1,N)
 2080 FØRMAT (1)I8)
 2010 CØNTINUE
      PAUSE
      READ (2,2020) IFLAG
 2020 FØRMAT (79X , I1)
      IF ( IFLAG - 2 ) 2030,10,2030
 2030 CALL EX+T
      END
```