MASTER

**PLANNING, SCHEDULING, AND CONTROLLING
AN ENGINEERING DESIGN GROUP**

E. E. Choat

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE Y-12 PLANT

operated for the **ATOMIC ENERGY COMMISSION** *under* **U. S. GOVERNMENT Contract W-7405 eng 26**

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CARBIDE**

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PLANNING, SCHEDULING, AND CONTROLLING
AN ENGINEERING DESIGN GROUP

E. E. Choat

This report is based on a study by the author as partial fulfillment of requirements for the degree of Master of Science in Industrial Management from The University of Tennessee.

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ABSTRACT

The objective of this study was to develop an improved planning, scheduling, and control system for use in an engineering design section, and to evaluate the effectiveness of this system with respect to changes in productivity.

Prior to 1962, no formalized procedures for planning or for establishing a priority of work existed, but a formal scheduling procedure did exist.

Early in 1962, a new planning, scheduling, and control system was developed and initiated. The system included a procedure for investigating new job assignments, the Critical Path Method technique to plan all jobs, a computerized scheduling program, and a control system built into a routine review procedure.

To evaluate the effect of these changes, production records were analyzed to determine the productivity of the section for a period encompassing one year prior to the changes and four years after the changes. These data indicate that there was a significant decrease in the number of manhours spent per drawing produced following the initiation of the newly developed planning, scheduling, and control system.

It is concluded that the changes made in the planning, scheduling, and control system have contributed significantly to this increase in productivity. Those elements that are viewed as having been improved and which might be expected to produce an increase in efficiency are: planning, scheduling, control, coordination, communications, job investigation, and job knowledge.

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TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION	1
Statement of the Problem.	3
Study Procedure	4
Definition of Terms.	4
Organization of the Thesis	7
II. THE ENVIRONMENT OF THE STUDY SECTION	9
Design Engineering Division	9
The Study Section	13
Planning, Scheduling, and Control Practices	
Prior to 1962	15
Planning, Scheduling, and Control Practices	
Subsequent to 1961	18
The Study Period	19
Division Work Measurement	19
III. A MANAGERIAL CONTROL SYSTEM.	22
Elements of the Critical Path Method	22
Arrow Diagramming	24

CHAPTER	PAGE
Planning	28
Scheduling	30
Multiproject Scheduling	35
Resource Allocation	35
Description and Application of the Developed System	37
Investigation of the Problem	37
Planning and Resource Allocation	38
Scheduling of Resources	42
Control Information	46
Project Review	50
Program Update	52
IV. PRODUCTIVITY ANALYSIS	65
Derivation of Output Indices	65
Indices of Productivity	65
Index of Drawing Time	66
Index of Engineering Time	68
Index of Nondrawing, Nonengineering Time	70
Index of Total Time	72
V. SUMMARY AND CONCLUSIONS	74

CHAPTER	PAGE
Summary	74
Conclusions	75
Planning	75
Scheduling	76
Control	76
Coordination	76
Communication	77
Investigation	77
Job Knowledge	78
BIBLIOGRAPHY	79
APPENDIX	82

LIST OF TABLES

TABLE		PAGE
I.	Production Summary of the General Mechanical Engineering	
	Department - Time Distribution (First Quarter 1965)	84
II.	Production Summary of the General Mechanical Engineering	
	Department - Completed Drawings (First Quarter 1965)	86
III.	Production Summary of the General Mechanical Engineering	
	Department - Equivalent Production (First Quarter 1965)	90
IV.	Summary Production Report - Average Drawing Time	92
V.	Summary Production Report - Average Engineering Time	93
VI.	Summary Production Report - Average Nonengineering,	
	Nondrawing Time	94
VII.	Summary Production Report - Average Total Time	95

LIST OF FIGURES

FIGURE	PAGE
1. Membership of Study Section	14
2. Work Order Schedule	17
3. An Engineering Job Plan	29
4. A Graphical Engineering Design Schedule	32
5. A Calculated Engineering Design Schedule	34
6. Critical Path Job Plan	40
7. Data Input Sheet	41
8. Group Weekly Schedule	44
9. Resource Weekly Schedule	45
10. Job Summary	47
11. Manpower Summary	49
12. Summary Project Schedule	51
13. Data for Updating	53
14. Restart a Job	55
15. Update an Activity	56
16. Update a Job	57
17. Add or Delete an Activity	59

FIGURE	PAGE
18. Change a Priority	60
19. Delete a Job	62
20. Add a New Job	63
21. Final Input	64
22. A Comparison of Average Time Spent Drawing	67
23. A Comparison of Average Time Spent Engineering	69
24. A Comparison of Average Nondrawing, Nonengineering Time	71
25. A Comparison of Average Total Time Spent	73

CHAPTER I

INTRODUCTION

Many functions of a physical nature are conveniently expressed and defined by describing their relationship to other functions. For example, a flow of water through a pipe might be expressed as a function of the area and velocity. In mathematical notation this general relationship might be expressed as $F(Q) = f(A, V)$. Q is defined as flow, A is the area of the pipe, and V is the velocity. The exact relationship is determined and described by the equation $Q = AV$. If the area and velocity can be measured, then a precise answer is attainable. Physical science is devoted to such problems. Establishment of relationships and the determination of the value of each element of the equation is a requirement for exact results.

In comparison, the management function has been defined in such general terms as, "The function of getting things done through people."¹ Some commonly discussed factors of the managerial function are: planning, organizing, staffing, and controlling. In mathematical terms then, the managerial

¹ Harold Koontz and Cyril O'Donnell, Principles of Management (New York: McGraw-Hill Book Co., Inc., 1959), p. 1.

function might be expressed as $F(M) = f(\text{planning, organizing, staffing, controlling, etc.})$.

The problem that scientific management has in using the less precise managerial equation is one of a definition of terms. Many attempts have been made to more fully define these factors. Brown's "96 Principles of Management"² and Koontz's "Principles of Planning"³ are examples of attempts. While these attempts have been extremely useful contributions to the general body of knowledge, none have approached the exactness of the definition required for a mathematical equation. Therefore, no exact managerial formula can exist and no precise answers may be calculated.

Yet, in some manner, both the scientist and the manager must find specific solutions to problems. Where the tools of the scientist are facts and formulae, the tools of the manager are theory, opinions, truisms, bias, intuition, observation, and experience. Where the scientist expresses expected results in relatively absolute terms, the manager is uncertain of the outcome and simply hopes for an improvement.

²Alvin Brown, Organization of Industry, (New York: Prentice-Hall, Inc., 1947).

³Harold Koontz, "A Preliminary Statement of Principles of Planning and Control," (Los Angeles: University of California, n.d.).

All is not lost, however, for those expousing scientific methods. If it is assumed or can be shown that the elements of the general managerial equation are positively correlated with $F(M)$, then an improvement of any element will result in an improvement in the desired direction. The manager, then, may feel that this approach is sufficiently scientific if he can reasonably predict the direction of change even though he has no means of estimating the magnitude.

In the real world of business then, the manager must be content with inexactness and uncertainty. He must recognize that the only means for improvement lies in the application of management tools and theory to develop techniques that might be logically expected to improve one or more factors of the managerial equation. He must realize that the only certainty gained in the management function is from the observation of actual results from applied techniques. Even then, it is unlikely that the manager can accurately assess the exact effect of any single action, although the change in the total situation may be quite clear.

I. STATEMENT OF THE PROBLEM

The objective of this study was to develop an improved planning, scheduling, and controlling system for use in an engineering design section,

and to evaluate the effectiveness of this system with respect to changes in productivity. Available management theory and tools were utilized to develop a system which was expected to bias several factors of the managerial equation in the desired direction. The techniques used were intended to provide for improved planning, scheduling, coordination, job knowledge, communication, job investigation, and control. In summary, the system was intended to provide for improved utilization of resources; i.e., people.

II. STUDY PROCEDURE

The procedure used in this study consisted of: (1) recognition of possible improvements from an analysis of an existing situation, (2) designing and initiating measures expected to improve the situation, and (3) evaluating the results over a period of time. An existing work measurement program was used to determine the manhours spent per unit output prior to and subsequent to the installation of the new planning, scheduling, and control system.

III. DEFINITION OF TERMS

Activity - A task or job in network planning. Activities or jobs are represented by identified arrows.

CPM - Critical Path Method - A recently developed technique of planning, scheduling, and controlling organized efforts, such as construction, maintenance, and engineering projects.

Critical path - The path (series of activities) through the network which requires the greatest amount of time. Delays in this path will cause extension of the project completion date.

Design engineer - The person within the study group having major responsibility for design. The engineer ordinarily supervises the preparation of drawings in addition to making calculations, preparing specifications, etc.

Draftsman - The person within the study group having the responsibility for the preparation of drawings. He may also have the responsibility for some design.

Dummy - An activity with zero duration which requires no work. Dummy activities are used in the network to keep the sequence logically correct or to keep activity identification unique.

Duration - The estimated time required to perform an activity.

Early finish time - The earliest time an activity may be completed.

Early start time - The earliest time an activity may be started.

Job estimate - An estimate of the expected time required to complete a task.

Float - The length of time that an activity may be delayed without affecting subsequent activities.

Index number - See priority number.

Late finish time - the latest time an activity may be completed without delaying completion of the project.

Late start time - The latest time an activity may be started without delaying completion of the project.

Network - A graphic presentation of the individual activities, their sequence, and their interdependencies, which make up a project.

Priority number - A number, assigned to work request to indicate level of importance. The lower the number the higher the priority.

Priority system - An order-of-importance-ranking-of-work-orders system used by the Engineering Division management.

Project engineer - An engineer assigned the responsibility for overall coordination of projects. The project engineer may be any one of several people of another department.

Resources - Draftsmen and engineers which are assigned to the Study Section.

Study section - a design section of the Engineering Division, Y-12 Plant, Union Carbide Corporation, Oak Ridge, Tennessee. The group is com-

posed of approximately 12 engineers and draftsmen. The plant is operated for the United States Atomic Energy Commission.

Updating - The process of changing durations of activities, and at times replanning the project in light of how activities are progressing.

Work order - See work request.

Work order number - A number associated with work orders for identification purposes.

Work request - A written request authorizing specific work requirements. Synonymous with work order.

IV. ORGANIZATION OF THE THESIS

Chapter II is concerned with the environment in which the Study Section functions. A brief discussion of the overall engineering organization and a description of an existing work measurement program are presented to provide an appreciation for the group's situation. In addition, the study section, the study period, and pertinent details regarding the group's planning, scheduling, and controlling activities prior to 1962 are discussed.

Chapter III discusses the developed planning, scheduling, and control system. Included are the basic concepts of the Critical Path Method of planning

and scheduling which have been applied in this case, and the details of the developed system as applied in an engineering design section.

Chapter IV contains several indices of performance of the study section. These were derived from data from the existing work measurement program and are utilized for evaluating the effectiveness of the developed planning, scheduling, and control system.

Chapter V consists of a summary and conclusions.

CHAPTER II

THE ENVIRONMENT OF THE STUDY SECTION

The objectives of this chapter are to describe the environment in which the study group exists, and to provide background data on the study group itself. What follows is a discussion of the Engineering Division; a description of a division work measurement program; an identification of the section studied and its planning, scheduling, and control activities; and a definition of the study period.

I. DESIGN ENGINEERING DIVISION

The study group is a part of the Design Engineering Division of the Y-12 Plant, located in Oak Ridge, Tennessee. The plant is operated by the Nuclear Division of Union Carbide Corporation for the United States Atomic Energy Commission. During the study period, the normal plant working force was approximately 4,500 people.

The Design Engineering Division is a relatively large organization engaged in a variety of engineering activities. It employs approximately 150 people on a full-time basis. Approximately one half of these are engineers. The other half are primarily draftsmen.

The chief function of the Division is to provide design engineering as required for plant maintenance, and to provide architect engineering services as required for plant expansion projects. In addition, the Division provides some engineering services for other plants within the Nuclear Division and other governmental agencies. During periods of peak demand for engineering service, the Division engages assistance from other plants and from outside engineering firms.

The division work load is adjusted such that the employment level is almost constant. Essentially constant employment levels in previous years is indicated by the number on the Division payroll at midyear as follows:

<u>Year</u>	<u>Number Employed</u>
1961	155
1962	154
1963	161
1964	157
1965	144

The division is subdivided into five design departments. These departments are organized along more-or-less specialized lines in order to maximize the contribution of groups and individuals. These specialized subunits

or departments are: Engineering Mechanics, General Mechanical Engineering, Civil and Architectural, Electrical, and Instrumentation.

Although organizationally separated, these departments cannot function independently of others. Completeness of the design requirements, mutual needs of other design capabilities, coordination, and compatibility of all phases of design are such that very close cooperation between departments is mandatory.

To achieve the required cooperation, the equivalent of design teams are formed for each engineering project. Resources are allocated to projects from each design department as required to accomplish the tasks at hand. For example—to air condition an existing conference room, the services of the General Mechanical, Electrical, and Engineering Mechanics Departments might be required. The General Mechanical Department would be responsible for the basic design, procurement of equipment, and perhaps project coordination; Electrical would provide electrical power for motors and controls; and Engineering Mechanics would design the required piping systems necessary to deliver steam and water to the project. Each specialized group would produce such drawings and specifications as necessary to define the work to be done. Contributions from all groups would be combined by the Project Engineer to form a complete design package. Although the arrangement is somewhat

along task-force lines, no formal lines of organization or authority are altered by the formation of design teams.

Departments are further subdivided into Sections. There are no general rules for the organization of sections. Some are simply an arithmetic division of the department, some are divided according to specialty, and some according to customer areas. During the past five years there has been a total of approximately twenty sections in the Division, with an average membership of approximately eight people each. Some sections have as few as five. Others have more than ten. The Study Section, with a membership of twelve, has been the second largest of the Division.

Project Engineering is a key coordinating department closely associated with the Division. This department performs liaison effort between Design Engineering and such associated groups as customers, contractors, and the Atomic Energy Commission. Project engineers are responsible for establishing new project criteria, assisting in arranging for funds, maintaining a work-order control system, and coordinating design and construction efforts. The project engineer exercises no direct authority over the design groups, but does have considerable influence in a functional capacity.

II. THE STUDY SECTION

The Study Section is the Environmental Control Section, which is a part of the General Mechanical Engineering Design Department. The section normally consists of three engineers, eight draftsmen, and one supervisor for a total of twelve people. The group is engaged in doing design tasks as required within their somewhat specialized category of work. Output from the group consists of drawings, specifications, bills of material, and engineering reports, as is typical for other engineering groups both within and outside the Division.

The section was reorganized in January 1962. Shortly thereafter, the newly developed planning, scheduling, and control system was initiated.

During the study period, membership in the Section remained reasonably constant. While there have been some arrivals and departures of minor participants, shifts of major performers were not experienced until late in 1965 and early 1966. Membership of the Study Section is outlined in Figure 1. Approximate dates of entry into and departure from the Section are shown for each member.

Work requests are made of the Engineering Design Section on standard request forms which are processed through the Project Engineering

E — Engineer.
 F — Designer
 D — Draftsman
 CO — Temporary Employee
 S — Supervisor
 D-L — Draftsman on Loan

FIGURE 1
MEMBERSHIP OF STUDY SECTION

Department. These requests include work order numbers, preliminary estimates of cost, and hours of engineering required (most likely the project engineer's best guess), names of the project engineer and customer, the requested completion dates, and narrative descriptions of the work to be done. It is common practice to assign new work orders to specific engineers who then assume a major responsibility for completion of the design.

The Section work load is complex and constantly changing. It is normal for the total work load to consist of many projects of varying sizes, requirements, and degrees of urgencies. Normally there is a queue or "backlog" equivalent to two or more months of full-time effort. Projects are being added and completed continuously. Customer preferences are often changing. Of the total situation, the most stable factor is the available engineering work force which may be applied to the problem. In this situation of continuous change, an efficient method of planning, scheduling, and controlling activities is needed.

Planning, Scheduling, and Control Practices Prior to 1962

Prior to 1962 there were no formalized procedures for either investigating or planning the work to be done. Normally, work orders were

assigned to an engineer who then contacted the project engineer or customer to determine the scope of the work and the appropriate action to take. The engineer was not required to prepare written plans of work or estimates of resources needed. Estimates of the time required and the completion date listed on the work order were assumed adequate and attainable.

The major vehicle for scheduling work was a work-order schedule form, Figure 2. On this form, all planning and scheduling information was recorded. Included was a list of all work-order numbers, building identifications, requested completion dates, job titles, and a listing of resources, i.e. engineers and draftsmen, of the section.

Scheduling of work was done in a weekly meeting of the section head and all engineers. At this time, a work schedule was made for the following week. Each job was reviewed and manpower assigned as seemed appropriate until all resources had been assigned a full 40 hours of work. For example—on the first job (Figure 2), design engineer ITL was scheduled 10 hours and draftsman KES for 40 hours. Copies of the completed schedule were made for each individual of the section.

Prior to 1962, no formal system for establishing priorities existed. Although no formal ranking of jobs existed, the equivalents of priorities were established during the scheduling process. These "priorities" were determined

Date _____ Sheet _____

Week of _____, 1961

W.O.	C.O.	Bldg.	Compl. Date	Description	D.E.	DEH	KES	GHK	LHW	CRF	Remarks
S-6234		9247	3-6-61	Air Condition Metallurgy Laboratory	ITL	10	40				
A-30623		9210	6-21-61	Hood Exhaust	JHC	20	40				
S-4293	E-723	9209	1-27-61	Heat Pump Shop	PEE	20		20			
S-293	E-3719	9206	5-3-61	Exp. Rec. Area	MLG	10			10		
S-B926		9203	6-6-61	Be LB Mill	REP	30				30	

FIGURE 2
WORK ORDER SCHEDULE

jointly by the engineer and section head. Major influences on decisions to work or not work a job were: a personal choice, relationships between customers and section personnel, and pressures from the organization. A major pressure source was from project engineers. It was customary for project engineers to expedite their jobs by personal influence through pressures exerted through line organization or other means. As a consequence, popularity of jobs sometimes suffered drastic increases or decreases. For this reason, interruptions of work in progress were not unusual.

Prior to 1962, no formal system of control existed. Control of the section was maintained by day-by-day contact with individuals of the section. Corrective measures were taken as the need arose.

Planning, Scheduling, and Control Practices Subsequent to 1961

Early in 1962 a new planning, scheduling, and control system was initiated in the study section. The system included a procedure for investigating new job assignments, the Critical Path planning technique to plan all jobs, a priority system of ranking for all jobs, a computerized scheduling program, and a control system built into a routine review procedure. This system is fully described in Chapter III.

III. THE STUDY PERIOD

Observations and data for this study were gathered over a period of five years, beginning in 1961. The beginning date was established by the availability of historical production data for the Engineering Division. The data come from records of a work measurement program initiated in 1961.

Two factors account for the decision to terminate the study period at the end of 1965. First, an adequate period of time had elapsed to establish trends which might develop in the results. Secondly, major losses of key members of the Study Section made continued comparison less significant. For example, one of three engineers of the group was transferred from the group in July 1965. A second engineer was lost to the group in January 1966 by death. In addition, two draftsmen left the group early in 1966. Replacements were made with significantly different personnel after a long period of time.

IV. DIVISION WORK MEASUREMENT

A work measurement program for evaluating the output of the Division was initiated in 1961 and functioned from that time throughout the Study Period.⁴

⁴Clayton B. Tolliver, "A Work Measurement Program" (Unpublished notes on techniques developed for the Y-12 Engineering Division, Union Carbide Corporation, Oak Ridge, Tennessee).

The program was a procedure which provided for routinely collecting records of drawings produced along with time spent to produce these drawings. This permits the determination of manhours spent per drawing by engineers, draftsmen, and supervisors.

Basic data for this program were recorded on weekly time cards. All employees were required to fill out a card each week. Data on the card included: employee's name, badge number, work order on which time was spent, drawing on which time was spent, type of activity (i.e., drafting, engineering), and the amount of time per day.

Types of activities recorded by draftsmen, engineers, and supervisors differed. Draftsmen categorized time spent as: drawing time, nondrawing time, revision time, and absence. Categories indicated by engineers were: engineering and absence. Supervisors categorized their time as engineering, absence, or other. These types of activities were designated on the time card by code letter.

Time card data were collected weekly, key punched, and assembled into quarterly reports by means of data processing equipment. In addition to a cumulation of drawings produced and a collection of total time for each individual, all time was categorized as to engineering, drafting, nondrafting, absence, and other time. It was, therefore, possible to list all individuals

of any department, tabulate drawings produced, and distinguish between different engineering categories of time.

As published, (see Appendix for format) the work measurement production report provided little guidance relative to the productivity of the study section. However, these data could be rearranged to provide a numerical index of productivity in terms of manhours spent per drawing produced. Output indices derived from this source are presented in Chapter IV.

CHAPTER III

A MANAGERIAL CONTROL SYSTEM

The objective of this chapter is to describe the managerial control system developed to plan, schedule, and control the activities of an engineering design group. Preceding the presentation of the details of this system, pertinent aspects of the Critical Path Method of scheduling are discussed.

I. ELEMENTS OF THE CRITICAL PATH METHOD

In recent years a new system of project planning, scheduling, and control has come into existence and into widespread use in the construction industry. It is called the Critical-Path Method (CPM). CPM has proved to be an extremely useful planning tool. It enables a project manager (and every one else connected with the project) to see the interrelationships of the work elements which make up the whole project. CPM shows which work elements are critical to the completion of a project. It enables the most efficient use of equipment and manpower. It is one of the most effective tools yet devised for progress control.⁵

⁵Special Projects Office, Bureau of Naval Weapons, Department of the Navy, "'PERT' Program Evaluation Research Task, Summary Report, Phase I." (Washington: U.S. Government Printing Office, September 1958.)

Major contributions to this new technique, originating from two sources, were reported in 1957-1958. One effort, that may have begun as early as 1957 by M. R. Walker of E. I. duPont and J. K. Kelley, Jr. of Remington Rand Corporation, was reported in 1959.⁶ A parallel effort, begun on January 27, 1958 by the U. S. Navy in cooperation with the management consulting firm of Booz, Allen, and Hamilton, was reported in 1958.⁷ Development of this technique probably gained much impetus through its highly successful utilization by the Navy in the Polaris program.

Interest in and application of this technique in industry have been widespread and varied. Claims of considerable improvements in time and cost control for many types of activities continue to be reported. The continued interest attests to the value of the technique and to the ease of application by large numbers of individuals to a variety of problems.

The fundamental technique of the critical path method is the diagrammatic approach to expressing a planned sequence of events. The finished

⁶ J. E. Kelley, Jr. and M. R. Walker, "Critical Path Planning and Scheduling," Proceedings of the Eastern Joint Computer Conference, (December 1-3, 1959), pp. 160-173.

⁷ "PERT" Program Evaluation Research Task, Summary Report, Phase I, "loc. cit."

product—a critical path network or a critical path diagram—is composed of a maze of arrows combined in such a manner to express a sequential order for doing tasks involved in the project.

Elementary considerations of this technique which are pertinent to this study are: (1) arrow diagramming, (2) planning, (3) scheduling, (4) multi-project scheduling, and (5) resource allocation.

Arrow Diagramming

A single task within the network is expressed by a single arrow as shown:

The arrow is normally drawn in a dimensionless but directional manner. Although the arrow has no scalar time value, it does have directional value in that the tail denotes the beginning of a task while the tip designates the completion.

Common information listed with arrows or tasks are: (1) a verbal identification of the task represented, (2) a numerical identification, and (3) an estimate of the time required to perform the task. The verbal identification is normally written immediately above the arrow. Numerical identification

is established by assignment of a unique number to each end of the arrow.

Time estimates may be designated by a number enclosed in a box below the line. Thus, the following task might be described as Task A, or Task 3-4.

The estimated time required to complete

this task is 10 days. The numerical identification is required when using a computer to solve the network. In a general mathematical sense, this numerical identification is referred to as the $i - j$ identification. In practice, as in mathematical terminology, i , or the beginning number, is always less than j , the ending number. Strict adherence is required to indicate the direction of work.

In a categorical sense, only three types of arrows are needed to describe any project: (1) series, (2) parallel, and (3) dummy.

Two tasks to be done in series are represented as follows:

This notation would mean that Task A must be completed prior to Task B. Note that a computer can easily distinguish the correct sequence of work by a simple comparison of numbers, since all tasks are uniquely identified and work progresses from small to large numbers. This job plan would be logical when only one resource is available. Total project time is two hours.

A parallel sequence of tasks may be represented as follows:

This plan would be logical when two or more resources were available to do the work. The total project time would be one hour, or one half the plan with only one resource.

A dummy is a fictitious task having a duration of zero. It is represented by a dashed arrow:

Dummies are sometimes needed to complete a network, or to clarify the logic of the network. Completion of the network by means of a dummy is required by a computer checking procedure which says that for every "j" there must be an "i" of the same number (except for the last). Thus, in the following example a dummy is required to meet this criterion.

Without the dummy arrow, the computer would see:

<u>i</u>	<u>i</u>
1	2
2	3
2	4

and would recognize the diagram as incomplete because of no $i = 3$.

Planning

The finished job plan is simply a combination of series, parallel, and dummy arrows into a logical array of events. This logical arrangement might be derived in the following manner:

1. List all tasks of the project.
2. Select one task which can be done at the beginning of the project, and identify with one arrow.
3. Compare other tasks to determine which can be done simultaneously, can be done upon completion of Task 1, or must wait upon completion of other tasks. Add arrows to diagram according to decisions.
4. Consider all arrows added with respect to all others in the same manner that Task 1 was examined. Add to diagram.
5. Continue this repetitious process until all tasks are included in the plan.

The result of this procedure is illustrated in Figure 3. This plan describes the tasks involved in preparing an engineering design package. For this plan, it is assumed that resources are unlimited in quantity and that the only restraints are that the plan be both logically and diagrammatically correct.

FIGURE 3
AN ENGINEERING JOB PLAN

Diagrammatically, the plan is correct. It has a single beginning and end point. All tasks are uniquely identified numerically and verbally.

Logically, the plan seems to be sound. As planned, the only task which may be undertaken initially is Task 1-2 or Prel. Engr. Upon completion of preliminary engineering, Tasks 2-3 (Complete Design) and 2-4 (Begin Drafting) may be started. Accordingly, the remaining tasks would be completed in an orderly, stepwise manner as seemed logical to the planner.

It is important to note that the planning phase in this technique is done independent of scheduling and requires only that the planner consider the reasonableness of the plan. It is also important to note that planning is such that it must be done by human effort. Planning cannot be delegated to machines as can the scheduling function.

Scheduling

The first step in the scheduling process is estimating the amount of time required for each task. Each task is estimated separately and labeled accordingly. Estimated project duration may then be calculated according to both the job plan and the estimated duration of each task.

In the preceding job plan (Figure 3) the duration of each task is as follows:

<u>i</u>	<u>j</u>	<u>Identification</u>	<u>Duration</u>
1	2	Prel. Engr.	10
2	3	Complete Design	10
2	4	Begin Drafting	20
3	4	Dummy	0
3	7	Prepare Spec.	20
3	8	Prepare B/M	20
4	5	Complete Drafting	20
5	6	Check Dwgs.	8
5	8	Comment Dwgs.	10
6	8	Dummy	0
7	8	Dummy	0
8	9	Issue	8

Scheduling is a simple problem in arithmetic or graphics. It is the conversion of plans to time scales. The scheduling process may be illustrated graphically by rearranging the previous job plan in a modified form on the gantt chart as in Figure 4. This model was constructed by applying scalar values to each task in accordance with the estimated duration and arranging the tasks such that the logic of the job plan (Figure 3, Page 29) was maintained. As shown, all tasks begin immediately upon completion of the preceding requirements. According to the schedule, the project duration is 68 hours.

The terms of "critical path" and "float" describe concepts which have arisen from the scheduling activity. These are prominently illustrated in Figure 4 as a heavy solid line and a solid or dashed wavy line, respectively.

FIGURE 4
A GRAPHICAL ENGINEERING DESIGN SCHEDULE

The critical path, or longest series of tasks, is important to the project manager in that it focuses attention upon those tasks which determine the total project schedule. In practice, these critical items may be as few as 10 per cent of the total number of tasks. Float, the length of time an activity may be delayed without affecting subsequent activities, is important because it allows for flexibility in the schedule. Thus, the project manager is not required to begin each activity at the earliest possible time, but may instead delay the activity to a more convenient time.

Scheduling of critical path plans may also be done by computer. Where computers are available, it is common practice to transfer data from the job plan to data cards, calculate a schedule, and print in tabular form. Figure 5 illustrates a calculated schedule for the previous job plan in which Earliest Start, Earliest Finish, and Float have been calculated for each activity. Note that activities on the critical path have a Float of zero. A summation of the duration of these activities results in a project duration of 68 hours, as was found in the graphical schedule (Figure 4). In addition to these values, Latest Start and Latest Finish times are listed by most programs. These values are obtained by delaying all activities as much as possible.

i	j	Identification	Duration	Earliest Start	Earliest Finish	Float
1	2	Prel. Engr.	10	0	10	0
2	3	Complete Design	10	10	20	20
2	4	Begin Drafting	20	10	30	0
3	4	Dummy	0			
3	7	Prepare Spec.	20	20	40	20
3	8	Prepare B/M	20	20	40	20
4	5	Complete Drafting	20	30	50	0
5	6	Check Dwgs.	8	50	58	2
5	8	Comment Dwgs.	10	50	60	0
6	8	Dummy	0	58	58	2
7	8	Dummy	0	40	40	20
8	9	Issue	8	60	68	0

FIGURE 5
A CALCULATED ENGINEERING DESIGN SCHEDULE

Multiproject Scheduling

Multiproject scheduling refers to the scheduling of more than one project simultaneously. Although a common and worthwhile problem, little has been written on the subject. Many projects, considered simultaneously, become much more complicated than a single one, and would require a computer for making computations.

In practice, each project is planned and diagrammed without consideration of any other. All projects are then linked together in a manner judged appropriate by the decision maker. The relative importance of projects as decided by management would determine the connecting link provided in the computer program.

Resource Allocation

Resource allocation is a process of assignment. In the case of work scheduling, it is the assignment of people as individuals or as a group. It is a process which has been largely ignored by most authors but must inevitably be considered in the practical application. In the critical-path method of planning, it is the process of assigning resources to each task in the network.

Even in the simple case, resource allocation becomes a complicated and tedious problem in arithmetic. It becomes so burdensome a task that a computer becomes a highly desirable tool.

Computer programs have been written to accept resource assignment to each task of a critical path diagram and to do various computations. Some programs simply compute the manpower needed for each time interval of the project. Others subdivide total manpower by crafts. One difficulty highlighted by these types of calculations is that the manpower required by the plan is seldom a constant value. Instead, the calculated manpower requirements are more likely to be somewhat erratic. Since it is not desirable to vary the work force to meet erratic requirements, "smoothing" or "manpower leveling" techniques have been developed which reschedule the initial plan to achieve a more uniform work force.

A more uniform level of working force is achieved by rescheduling tasks of the job plan such that resources are used on a more uniform rate and the project is still completed on schedule. The existence of "float" in most tasks makes this procedure possible to a degree. Extensive computer programs have been written for such resource allocation.^{8, 9} By means of

⁸"Project Control Through Resources, Planning, and Scheduling Methods," (Fort Washington, Pennsylvania: Mauchly Associates, Inc., 1962).

⁹W. A. Gray and E. M. Kidd, "Critical Path Scheduling and Resource Leveling on an IBM 7090," Union Carbide Nuclear Company (March 20, 1962).

these programs, the computer is capable of computing an optimum level work force for any specified project duration. Widespread use of this degree of sophistication has not been observed.

II. DESCRIPTION AND APPLICATION OF THE DEVELOPED SYSTEM

Although the system that was developed is dynamic and constantly changing, it can be best described in terms of a sequence of events which was initiated with each work request. This series of events include: (1) an investigation of the problem, (2) planning and resource allocation, (3) scheduling of resources, (4) reviewing and revising plans, and (5) updating of plans.

Investigation of the Problem

An investigation of new work orders was conducted jointly by the section head and the engineer assigned to the job as they were received. The objective of the investigation phase was to determine the scope of the problem. It was intended to determine: the location of the work, magnitude of the project, reasonably definite requirements to be met, conditions at the job site, and any restrictions involved. The investigation took the form of a discussion with the project engineer, discussion with the customer, review of any preliminary

work, and/or field trip to the job site as seemed appropriate for a specific situation. Although tentative alternatives were discussed during the investigation, no attempt was made to make final design decisions unless the job was very simple. It was normal, however, to decide upon a general approach to the problem.

Planning and Resource Allocation

Planning for doing work was done for each job upon completion of the investigation phase. This process involved: the preparation of a critical path diagram which described the work to be done, estimating the amount of time required for each task, deciding upon a rate at which each task would be worked, and entering all of the foregoing planning decisions on a data card for computer processing.

All planning and estimating activities were completed by the engineer responsible for the job. It is important to note that the only considerations involved in the planning stage were to arrange a sequential array of events which seem logically correct and to estimate the time required to accomplish each task. No attempt was made to determine when a job might be either started or completed.

Review of the completed job plan and the allocation of resources were functions involving both the engineer and the section head. The review consisted of a check of the logic of the plan and the time estimates. Drastic changes, especially on time estimates, were rarely made to the plans submitted.

Resource allocation consisted of the assignment of specific people to each task in the project. Selections were made on the basis of individual ability, upon availability of those qualified, and upon the urgency of the job.

Figure 6 is an example of a completed job plan with all pertinent data indicated on the diagram. All tasks have been identified, numbered, estimated, assigned to specific resources, and assigned a rate of work. The practice used is commonly found except that a specific person has been assigned to the task and a rate at which the task is to be worked. For example, Activity 10-20 is a preliminary engineering activity assigned to JCC. The estimated time to complete the task is ten hours. The indicated rate is ten hours per week. All other activities are similarly identified. The plan was rarely used in this format, but instead was transferred to an input data sheet for computer processing.

An input data sheet is illustrated in Figure 7. The data sheet contains all the decisions recorded on the job plan. For example, line one (of the body of the form) contains all information regarding Activity 10-20. The task is

FIGURE 6
CRITICAL PATH JOB PLAN

Prel. Engr., the estimated manhours is 10, the desired work rate is 10 hours per week, and the assignment is given to JCC. In the work order information portion, the data sheet contains the work order number (Columns 2-13), identity of design engineer (Columns 14-16), identity of project engineer (Columns 17-19), priority index (Columns 20-22), and the job identification (Columns 32-49). It will be noted that both primary and secondary assignments were made. Responsibility for the entire project was assigned to the design engineer. Responsibility for individual tasks were assigned to either the design engineer or others.

Scheduling of Resources

Scheduling of resources was entirely a machine process. This process was governed by plans previously made for each job, the priority number assigned, and the availability of the resources. In essence, the computer looked at the most urgent job, assigned the desired manpower, and then moved to the second most urgent job. As each job was considered, manpower was assigned until no more was available.

Schedule information derived from basic data was arranged in three different formats: Group Weekly Schedule, Resource Weekly Schedule, and Job Summary.

Group Weekly Summary, Figure 8, lists all work scheduled for the Study Section for one week. Information listed on line 1 consists of: (1) identity of design engineer (JCC) in column 1 headed "DE", (2) under "Index" is the priority number 3, (3) under "Work Request" is work order number 98081-A-52, (4) under "PE" is the project engineer MAB, (5) under "I" and "J" are the identity numbers of an activity 10-20 in job plan 3, (6) under "Activity Identification", is the task of Prel. Engr., (7) under "EST" is the estimated time of 10 hours, (8) under "LEFT" is 0 manhours left after the current week, (9) under "RES" is the required resource JCC, (10) under "RATE" is 10 hours per week, (11) under "Man-Hrs. Assigned" is the assigned 10 hours, and (12) under "W. O. Title" is the title of the work order. In a similar manner, work scheduled on job 6 is shown on lines 2 and 3 in rank order. Distribution and use of Group Weekly Schedule is limited to the section head.

The Resource Weekly Schedule was derived from Group Weekly Schedule by sorting according to resource (Figure 9). Thus, all tasks assigned directly to any resource were printed on one sheet and arranged according to index number. In format, the result is the same as Group Weekly Schedule. The important difference is that it lists all tasks assigned as well as those scheduled. Distribution of Resource Weekly Schedule was made each week to each resource of the group and the section head. It was intended that this

WEEKLY SUMMARY A												
ACTIVITIES FOR WEEK ENDING OCT 23, 1965								FILE DATE OCT 15 1965				
DE	INDEX	WORK	PE	I	J	ACTIVITY	MAN-HRS	MAN-HRS	RES RATE	MAN-HRS	W O	TITLE
REQUEST			IDENTIFICATION			EST	LEFT	(PM/WK)		ASSIGNED		
JCC	3	98081-A-52	MAB	10	20	PREL ENGR	10.0	0.	JCC	10.0	10.0	DEV BIOCHEM LB9207
JCC	6	98082-A-52	MAB	10	20	ENGR	20.0	10.0	JCC	10.0	10.0	CELL CULTURE 9210
JCC	6	98082-A-52	MAB	10	30	DRAFT	60.0	0.	GHK	20.0	20.0	CELL CULTURE 9210
ITL	7	98083A-52	MAB	10	20	DRAFTING	40.0	0.	CLS	20.0	20.0	BIOMETRICS 9704-1
ITL	7	98083A-52	MAB	10	30	ENGINEERING	40.0	0.	ITL	20.0	20.0	BIOMETRICS 9704-1
ITL	16	34600-E-454	MAB	10	20	PREL ENGR	16.0	6.0	ITL	16.0	10.0	ANIMAL BARRIER 9207
ITL	18	101-E-175	WEG	10	16	DRAFT	200.0	80.0	ELE	40.0	40.0	DEV EQ LAYOUT 9202
ITL	18	101-E-175	WEG	10	20	CONSULT CO-OP	24.0	0.	KES	8.0	8.0	DEV EQ LAYOUT 9202
ITL	19	30800E 902	HMA	10	30	DRAFTING	64.0	32.0	DEM	32.0	32.0	PERCHLOR HOOD 9735
RCB	20	34600A-E455	MAB	10	20	INVESTIGATE	10.0	0.	RCB	10.0	10.0	RAC IMMUN LAB 9207
RCB	23	35087HQ4135	MAB	10	20	DRAFTING	16.0	0.	CLS	16.0	16.0	ENU PROBLEMS 9211
RCB	23	35087HQ4135	MAB	10	30	COST ESTIMATE	10.0	0.	RCB	10.0	10.0	ENU PROBLEMS 9211
JCC	33	4258-S-11	MCM	20	30	DRAFT + DESIGN	60.0	32.0	DEM	40.0	8.0	SHIELDED RM 9737
JCC	33	4258-S-11	MCM	20	60	AC SYS	20.0	0.	JCC	10.0	10.0	SHIELDED RM 9737
RCB	35	71035-A-52	MAB	10	30	COMP DRAFT	20.0	0.	KES	20.0	20.0	LIBRARY EXP 9207
RCB	35	71035-A-52	MAB	10	20	COMP DESIGN	10.0	0.	RCB	10.0	10.0	LIBRARY EXP 9207
JCC	49	346-E262	KDC	10	30	DRAFT	20.0	8.0	KES	20.0	12.0	PNEU THERMO BWING
ITL	62	98054-A-52	MCM	10	25	MASTER PLANS 9201-2	120.0	100.0	GHK	40.0	20.0	FIRE PROT ORNL
EFC	65	71038-A-51	MAB	10	20	ENGR AS REQD	80.0	60.0	EFC	5.0	5.0	RIO RES LAB 9207
RCB	68	2277-B-11	HMA	10	30	BAL + TEST	8.0	4.0	CLS	8.0	4.0	UT-AEC AS BUILT

FIGURE 8
GROUP WEEKLY SCHEDULE

GROUP WEEKLY SCHEDULE												
ACTIVITIES FOR WEEK ENDING OCT 23, 1965								FILE DATE OCT 15, 1965				
DE	RES	INDEX	WORK REQUEST	PE	I	J	ACTIVITY IDENTIFICATION	MAN-HRS EST	MAN-HRS LEFT	RATE	MAN-HRS ASSIGNED	W O TITLE
ITL	DEM	19	3080DE 902	HMA	10	30	DRAFTING	64.0	32.0	32.0	32.0	PERCHLOR HOOD 9735
JCC	DEM	33	4258-S-11	WCM	20	30	DRAFT + DESIGN	60.0	32.0	40.0	8.0	SHIELOED RM 9737
DEM	DEM	45	33062-A-51	HAB	10	20	CUT COST EST	16.0	16.0	16.0	0.	LARGE ANIMAL QTRS
DEM	DEM	608	30700X62965	HMA	10	20	BALANCE SYS	16.0	16.0	8.0	0.	3RD FL OFF 9201-3
DEM	DEM	612	1999W25024	WCM	10	20	INVESTIGATE-ETC	80.0	54.0	40.0	0.	FIRE DAMPERS 9737
DEM	DEM	614	1999W25024	WCM	10	20	INVESTIGATE-ETC	40.0	40.0	40.0	0.	FIRE DAMPERS 9203
DEM	DEM	620	1999W25023	WCM	10	20	ONE LINE DIA	200.0	200.0	40.0	0.	VENT SURVEY 9203

FIGURE 9
RESOURCE WEEKLY SCHEDULE

schedule provide a concise list of management's desires ranked in priority order to each individual within the group. It was intended that the list show the expected performance for the week schedule, as well as a listing of all tasks currently assigned. Thus, in the example (Figure 9), DEH was assigned a responsibility for seven tasks in seven different jobs. Of these, it was expected that he would spend 32 hours on job 19 and 8 hours on job 33 for a total of 40 hours. DEH was not expected to make any effort toward other tasks listed as there would be no time available.

A Job Summary (Figure 10) was printed for each job in the system. The information contained thereon was essentially basic data as recorded on the data input sheet, and the calculated scheduled times as indicated by dates listed. Distribution of Job Summaries were made to the engineer assigned to the job and to the section head.

Control Information

In this system, the control information available to the section head consisted of the Group Weekly Summary, Resource Weekly Schedule, and Job Summary, previously described. From these the section head was able to quickly ascertain the jobs that are scheduled, individual job assignments, and the status of any particular job. In addition, other useful data were derived

7

INDEX	WORK REQUEST	PE	DE	JOB IDENTIFICATION	HRS-ACC
3	98081-A-52	MAB	JCC	DEV BIOCHEM .89207	

I	J	EST-HRS	(H-H/WK)	RESOURCE	ACTIVITY IDENT	STARTING DATE	FINISH DATE
10	20	10.00	10.00	JCC	PREL ENGR	OCT 23,1965	OCT 23,1965
20	30	40.00	40.00	GKK	AC OUGS	OCT 30,1965	OCT 30,1965
20	40	10.00	10.00	JCC	DESIGN AC SYS	OCT 30,1965	OCT 30,1965
30	70	80.00	40.00		COMMENT	NOV 6,1965	NOV 13,1965
30	80	8.00	8.00	RCB	CHECK	NOV 6,1965	NOV 6,1965
40	50	20.00	20.00	JCC	COLD RM SPECS	NOV 6,1965	NOV 6,1965
50	60	20.00	20.00	JCC	BM REFRIGS + MISC	NOV 13,1965	NOV 13,1965
60	80	-0.	-0.		DUMMY		
70	80	-0.	-0.		DUMMY		
80	90	8.00	8.00	JCC	ISSUE	NOV 20,1965	NOV 20,1965

FIGURE 10
JOB SUMMARY

from the same basic input. Two of these were the Manpower Summary and the Summary Project Schedule.

A Manpower Summary was calculated for each resource of the section. Figure 11 is an example in which the status of two resources - RCB and ITL - are shown for a period of six weeks. The name listed in the Resource column is a member of the study section. The symbol RCB is simply the initials of Roy C. Brown. "Gross M-H" is the manhours which this person was expected to work during the week. "Holiday" listed hours deducted from the working schedule for plant holidays. "Vacation" is the time in hours scheduled away from work for vacation. "Cushion" is nonscheduled time. For engineers, the appropriate cushion time was estimated to be ten hours per week. No cushion was allowed for draftsmen. "Net M-P" is gross M-H minus cushion or manhours available for scheduling purposes. "M-P Scheduled" is the manpower actually scheduled by the computer. "% Scheduled" is M-P scheduled divided by net M-P. "Week Ending" indicates the work period for which the calculation was made. The number of weeks calculated may be more or less as specified in the update data. The Manpower Summary was useful to the section head because it provided a means of ascertaining the magnitude of the work load of any individual on a current and extended basis. New jobs were ordinarily assigned

MANPOWER SUMMARY							FILE DATE OCT 15 1965				
RESOURCE	SYMBOL	GROSS M-D	LOAN	HOLIDAY	VACATION	CUSHION	NET M-P	M-P SCHEDULED	% SCHEDULED	WEEK	ENDING
BROWN*	RCB	40.00	0.	0.	0.	10.00	30.00	30.00	100.00	OCT	23, 1965
BROWN*	RCB	40.00	0.	0.	0.	10.00	30.00	18.00	60.00	OCT	30, 1965
BROWN*	RCB	40.00	0.	0.	0.	10.00	30.00	21.00	70.00	NOV	6, 1965
BROWN*	RCB	40.00	0.	0.	0.	10.00	30.00	26.00	86.67	NOV	13, 1965
BROWN*	RCB	40.00	0.	0.	0.	10.00	30.00	0.	0.	NOV	20, 1965
BROWN*	RCB	40.00	0.	8.00	0.	8.00	24.00	10.40	43.33	NOV	27, 1965
RESOURCE	SYMBOL	GROSS M-D	LOAN	HOLIDAY	VACATION	CUSHION	NET M-P	M-P SCHEDULED	% SCHEDULED	WEEK	ENDING
LITTLE*	ITL	40.00	0.	0.	0.	10.00	30.00	30.00	100.00	OCT	23, 1965
LITTLE*	ITL	40.00	0.	0.	0.	10.00	30.00	30.00	100.00	OCT	30, 1965
LITTLE*	ITL	40.00	0.	0.	0.	10.00	30.00	30.00	100.00	NOV	6, 1965
LITTLE*	ITL	40.00	0.	0.	0.	10.00	30.00	30.00	100.00	NOV	13, 1965
LITTLE*	ITL	40.00	0.	0.	0.	10.00	30.00	30.00	100.00	NOV	20, 1965
LITTLE*	ITL	40.00	0.	8.00	0.	8.00	24.00	16.40	68.33	NOV	27, 1965

* Personnel names are fictitious.

FIGURE 11
MANPOWER SUMMARY

to those resources having the smallest work load. The example clearly indicates the desirability of assigning work to RCB in lieu of ITL.

The Summary Project Schedule (Figure 12) is an arrangement of data for the convenience of the section head. It lists all jobs in priority order along with the scheduled Start and Finish times. As shown, calculations were made for a six-week period. Consequently, no date is shown if the scheduled date is larger than the calculated period.

The Summary Project Schedule was useful because it provided a convenient prediction of start and finish times for all jobs. More importantly the schedule was based upon planning data of sufficient detail to assure that the promised schedule could be met.

Project Review

Each week the entire work load was reviewed. Each engineer met separately with the section head to review and revise each and every job. During the review any aspect of the job was open for discussion, all plans were subject to revision if required, and all estimates were subject to correction. Questions of a technical nature were discussed along with planning and scheduling considerations. It was a time of consultation, evaluation, and correction. Complete frankness and honest judgments were encouraged with no stigma

INDEX		FILE DATE OCT 15 1965						
DE	INDEX	WORK REQUEST	PE	JOB IDENTIFICATION	START	FINISH	SECT-ID	HRS-ACC
JCC	3	98081-A-52	MAB	DEV BIOCHEM L89207	OCT 23, 1965	NOV 20, 1965		
JCC	4	98082-A-52	MAB	CELL CULTURE 9210	OCT 23, 1965	NOV 20, 1965		
ITL	7	98083A-52	MAB	BIOMETRICS 9704-1		NOV 13, 1965		
ITL	16	34600-E-454	MAB	ANIMAL BARRIER 9207	OCT 23, 1965	OCT 30, 1965		
ITL	18	101-E-175	MEG	DEV EQ LAYOUT 9202				
ITL	19	30800E 902	HMA	PERCHLOR HOOD 9735	OCT 30, 1965	NOV 20, 1965		
RCB	20	34600A-E455	MAB	RAD IMMUN LAB 9207	OCT 23, 1965	OCT 23, 1965		
RCB	23	35087MD4135	MAB	EMU PROBLEMS 9211	OCT 23, 1965	NOV 6, 1965		
JCC	33	4258-S-11	WCM	SHIELDED RM 9737				
RCB	35	71035-A-52	MAB	LIBRARY EXP 9207	OCT 23, 1965			
ITL	39	19225-11	MAB	SERVICE FAC 9208				
DEM	45	33062-A-51	MAB	LARGE ANIMAL QTRS	NOV 6, 1965	NOV 6, 1965		
ITL	48	98060-A-52	MAB	CELL SYNCHRONY 9207				
JCC	49	346-E262	KCC	PNEU THERMO RHING	OCT 30, 1965	NOV 13, 1965		
KES	50	98054-A	WCM	FIRE PROT ORNL		NOV 20, 1965		
ITL	62	98054-A-52	WCM	FIRE PROT ORNL	OCT 30, 1965			
EEC	65	71038-A-51	MAB	BIO RES LAB 9207				
ITL	66	10775-11	MEG	LAB SERVICES 9752				
RCB	66	2277-B-11	HMA	UT-AEC AS BUILT	OCT 30, 1965			
RCB	69	98063-52-A	MAB	DEV BIO LAB				
ITL	80	7705-S-10	WCM	AIR PQ CONT 9401-3				
JCC	90	30399MD1219	MAB	BAL AIR LP 9207				
ITL	250	30802Y121G5	HMA	EST MOVE AC U 9735	NOV 20, 1965			
RCB	320	1999W25024	WCM	E PROT 9206				FIR

FIGURE 12.
SUMMARY PROJECT SCHEDULE

attached to being somewhat in error. The engineer was expected to recognize and raise the question of problems pertinent to the job. Jointly, the engineer and section head revised their plans accordingly. These decisions were then noted on the Job Summary printout. Possible decisions were: (1) restart a job, (2) change an activity, (3) add an activity, (4) change a priority, (5) delete a job, and (6) add a new job.

Program Update

With the exception of a few control cards, updating the program was a matter of transferring decisions made during the project review to data sheets, key punching, and rerunning the program.

The first card necessary is illustrated in Figure 13. Also shown on the data sheet are the instructions for properly writing the input data. The "1" in column 1 indicates that this is the first card in the deck. June 16, 1962, in columns 4-13, specifies the week for which calculations were to be made. The "1963" in columns 14-17 identifies the year following 1962. The "7" in column 20 specifies that calculations shall be made for 7 weeks. The "1" in column 23 requests a printout of the Group Weekly Schedule for one week. The "2" in column 26 requests a printout of the Resource Weekly Schedule for one week. The "1" in column 29 requests a printout of the Weekly Summary A

for one week. The "6" in column 35 requests a printout of the Manpower Summary for 6 weeks. June 6, 1962, in columns 36-44, is the file date. The "40" in columns 48-49 indicates a 40-hour work week.

Sometimes no work was done on a job. It was then convenient to restart the scheduling process for that one job only. The update notation for doing so in this system is illustrated in Figure 14. The "1" in column 1 says, "I would like to restart a job." The "430" in columns 20-22 names the job to be restarted.

Frequent updating of the single activities within a job was a normal requirement. Quite frequently, estimates of time requirements change. Also, it was sometimes desirable to change the rate of work or even the resource. Figure 15 illustrates the method for making these changes. The "2" in column 1 indicates an update. The "29" in columns 21-22 specifies the job. The "10" and "12" in columns 51-52 and 54-55 specify the particular activity of Job 29 to be changed. All other data—activity identification, mandays, rate, or resource—may be changed as desired.

"Update a job" is a term used in reference to changing work order identification information. A change in the work order number, change of the project engineer, or a change in job identification makes this capability necessary. Figure 16 illustrates the technique for doing so. The "2" in column 1 indicates

WORK ORDER										CROSS ORDER										PE	DE	INDEX	SPECIAL	SECT.	HR. ACC.	JOB IDENTIFICATION																					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48

		INDEX		SPECIAL		ACTIVITY IDENTIFICATION																				I	J	MAN-HOURS		RATE (M.H./WK.)		RESOURCE		REMARKS																															
1	2-19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66																	
1	4	3	0																																																														
<p style="text-align: center;">INSTRUCTIONS</p> <p>1. Column 1 must contain a 1 punch.</p> <p>2. Columns 20-22 must contain the job's index number.</p>																																																																	

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FIGURE 14
RESTART A JOB

[illegible]

FIGURE 15
UPDATE AN ACTIVITY

		INDEX		SPECIAL		ACTIVITY IDENTIFICATION																1		2		MAN-HOURS		RATE (H./WK.)		RESOURCE		REMARKS																	
1	2-19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	

INSTRUCTIONS

1. Column 1 must contain a 2 punch.

2. Columns 2-7 must contain the numerical part of the job's new work order number.
Columns 8-13 must contain the numerical and/or alphabetical part of the new work order number.

3. Columns 14-19 must contain the job's new coordinator.

4. Columns 20-22 must contain the project's present index number.

5. Column 25 must contain a 1 punch.

6. Columns 26-49 must contain the job's new identification.

7. Note: the job's index and the 1 punch in Column 25 controls the above information.

FIGURE 16
UPDATE A JOB

the update. The "101" in columns 20-22 specifies the job. Other data may be changed as desired.

It is almost impossible to foresee all tasks required in every job. The capability for adding to or deleting tasks from an existing plan was often required. The means for either adding or deleting is illustrated in Figure 17. The "3" in column 1 indicates an addition or deletion to the system. The "101" in columns 20-22 specifies the job in which the deletion is to be made. A "1" in column 25 indicates the addition of the activity described in subsequent columns. A "0" in column 25 would indicate a deletion.

Job priorities do change. Changes in priority occurred as a result of a re-evaluation of things to be done with respect to both new jobs and changing conditions. It became necessary, then, that the scheduling system of the study section incorporate a capability for quick adjustment for priority change. Figure 18 illustrates the ease with which this adjustment is made. The "4" in column 1 says, "I would like to change the priority of a job." The "101" in columns 20-22 specifies the job to be changed. The "20" in columns 24-25 is the new priority number.

Job plans are removed from the system only by instruction. If no instructions are given, the job plan will be repeated as previously written week after week. To remove or delete a job, it is necessary to indicate a

		INDEX				SPECIAL	ACTIVITY IDENTIFICATION																				I		J		MAN-HOURS				RATE (M.H./WK.)				RESOURCE				REMARKS																							
1	2-19	20	21	22	23	24	25		26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66																	
3		1	0	1		1			P	R	E	P	A	R	E		S	P	E	C													1	3		1	5			9	0			3	0	F	C	8	ADD																	
3		1	0	1		0																											1	3		1	5											DELETE																		

	INDEX				SPECIAL	ACTIVITY IDENTIFICATION																												I	J	MAN-HOURS				RATE (M.H./WK.)		RESOURCE		REMARKS																					
1	2-19	20	21	22	23	24	25			32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66																					
4		1	0	1		2	0																																																										
INSTRUCTIONS																																																																	
1. Column 1 must contain a 4 punch.																																																																	
2. Columns 20-22 must contain existing priority number.																																																																	
3. Columns 23-25 must contain new priority number.																																																																	

09

deletion by placing a "5" in column 1 and the index number of the completed job in columns 20-22. This procedure is illustrated in Figure 19.

The procedure for adding a new job is illustrated in Figure 20. The "6" in column 1 indicates a "new job." "Project Information", i.e., Work Order, Project Engineer, Design Engineer, Index Number, and Job Identification, is written on the top line in accordance with the detailed instructions shown. "Activity Information" is information taken from the completed critical path plan.

The last card is a programming requirement and is always written the same (Figure 21). The "9" in column 1 says to the computer, "These are all the data. Go to work."

As demonstrated, the mechanics of updating is a simple, straightforward procedure which was accomplished with an expenditure of a minimum amount of time. Preparation of the data input sheets required approximately 30 minutes of the section head's time.

-	WORK ORDER						CROSS ORDER						PE	DE	INDEX	SPECIAL	SECT.	HR. ACC.	JOB IDENTIFICATION																															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	
6	2	4	4	9	-	S								H	M	A	J	C	C	I	2	4																												

		ACTIVITY IDENTIFICATION																														I		J		MAN HOURS		RATE (M.H./WK.)		RESOURCE		REMARKS																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
1	2																															31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																													
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INSTRUCTIONS

Project Information

- Column 1 must contain a 6 punch.
- Column 2-7 must contain the numerical part of the project's new workorder number. Columns 8-13 must contain the numerical and/or alphabetical part of the new work order number.
- The project engineer must be contained in columns 14-16.
- The design engineer must be contained in columns 17-19.
- The project index number must be contained in columns 20-22.
- The project identification must be contained in columns 32-49.

Activity Information

- Column 1 must contain a 6 punch.
- Columns 32-49 contain the identification for the activity.
- Columns 50-52 contain the "i" number for the activity.
- Columns 53-55 contain the "j" number for the activity.
- Columns 56-59 contain the "man-days" quantity for the activity.
- Columns 60-63 contain the rate of activity.
- Columns 64-66 contain the "resource" assigned to the activity.

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FIGURE 20
ADD A NEW JOB

CHAPTER IV

PRODUCTIVITY ANALYSIS

I. DERIVATION OF OUTPUT INDICES

In this study, it was desirable to derive some indicator of performance for the entire design section, including engineers, draftsmen, and supervisors to provide some measure of the effectiveness of the group effort. Accordingly, basic data similar to that contained in Tables I, II, and III, Appendix, were rearranged to permit a comparison of the rate of production, in manhours spent per unit output, of the study section on a year-to-year basis.

A summary of production data for twenty quarters and yearly summaries are contained in Tables IV, V, VI, and VII (Appendix). From this summary, evaluations may be made in terms of Drafting Time, Engineering Time, Nondrawing Time, or Total Time spent per drawing produced.

II. INDICES OF PRODUCTIVITY

Evaluations of the indices of drawing time; engineering time; non-drawing, nonengineering time; and total time follows.

Index of Drawing Time

Yearly averages (from Table IV, Appendix) of time spent on drawing tasks are illustrated graphically in Figure 22. Drawing time is that time spent actually making drawings of all kinds. Included is time spent making both new drawings and revisions. Time spent making smaller than E-size drawings and revisions has been converted such that all data are expressed in terms of a standard E-size unit. For example, two D-size drawings are considered equivalent to one E-size drawing. Within the work measurement system, only draftsmen may charge time to "D" and "R" categories.

No significant change in the time spent on drawing tasks is noted for any year. During four years, the rate of hours spent by the Study Section rose approximately 6 per cent above that of the 1961 rate and then decreased to approximately 10 per cent below. The 1962-1965 average for the study group was 22.5 hours compared to 22.9 hours in 1961.

It can be concluded that changes made during five years have had little effect upon the rate at which time was charged toward the production of drawings. Since no improved drafting techniques have been initiated in these groups, it is logical that time required to put lines on paper would not be less.

FIGURE 22
A COMPARISON OF AVERAGE TIME SPENT DRAWING

Index of Engineering Time

Yearly averages (from Table V, Appendix) of time spent doing engineering tasks are illustrated graphically in Figure 23. Engineering time is that time spent doing numerous engineering tasks. Included is time spent investigating, making calculations, meeting with customers, making studies, preparing specifications, and supervising the preparation of drawings. Within the framework of the work measurement system, only engineers charge time to the "E" category.

Time spent by the study group doing engineering tasks subsequent to 1961 is significantly less than the 1961 rate. On the average, time spent doing engineering by the study group during four subsequent years was 46 per cent less than the 1961 rate. The maximum was 52 per cent in 1965; the minimum was 37 per cent in 1964.

It can be concluded that changes made in the early part of 1962 resulted in the use of considerably less engineering manpower per drawing produced. An improved planning, scheduling, and control system could logically be expected to result in a more economical performance of engineering tasks.

FIGURE 23

A COMPARISON OF AVERAGE TIME SPENT ENGINEERING

Index of Nondrawing, Nonengineering Time

Yearly averages (from Table VI, Appendix) of time spent doing non-drawing tasks are illustrated graphically in Figure 24. This category includes time spent by engineers, draftsmen, and supervisors. Included is "N" time, "O" time, and "ABS" time. Charges to "O" time are made almost entirely by the group supervisor, and are, therefore, essentially a constant. Charges to "ABS" are for vacation, sick, and personal time of both engineers and draftsmen. Thus, charges to "ABS" time are also essentially constant. The significant variable of this category of time is that of "N" time.

A complete cycle is indicated by the data. A decrease of approximately 27 per cent was experienced in 1962, followed by a gradual increase to 43.0 manhours per drawing in 1965, which is almost the same as the 1961 rate of production. Both the sharp decrease and the constant increase thereafter seem consistent with the events of the period.

It may be concluded that changes in the early part of 1962 resulted in usage of significantly less time doing nondrawing tasks. It is reasonable to expect that an improved planning, scheduling, and controlling system would produce a more efficient utilization of time in this category.

FIGURE 24

A COMPARISON OF AVERAGE NONDRAWING,
NONENGINEERING TIME

Index of Total Time

Yearly averages (from Table VII, Appendix) of total time spent per drawing output is illustrated graphically in Figure 25. Included is the summation of drawing time; engineering time; and nondrawing, nonengineering time.

The indicated trend is characterized by a sharp decrease in rate of manpower utilization in 1962, compared to 1961, followed by an increase, as was found in the components. The maximum improvement was approximately 32 per cent in 1962. The 1965 production rate was approximately 21 per cent less than 1961.

It may be concluded that changes made in the early part of 1962 resulted in a significantly more efficient utilization of total manpower doing engineering tasks.

FIGURE 25

A COMPARISON OF AVERAGE TOTAL
TIME SPENT

CHAPTER V

SUMMARY AND CONCLUSIONS

I. SUMMARY

The objective of this study was to develop an improved planning, scheduling, and controlling system for use in an engineering section, and to evaluate the effectiveness of this system with respect to changes in productivity.

Prior to 1962, no formalized procedures were found for planning or for establishing a priority of work. Prior to 1962, there did exist a formal scheduling procedure.

Early in 1962, a new planning, scheduling, and control system was initiated. The system included a procedure for investigating new job assignments, the Critical Path Method technique, to plan all jobs, a computerized scheduling program, and a control system built into a routine review procedure.

To evaluate the effect of these changes, production records were analyzed to determine the productivity of the section for a period encompassing one year prior to the changes and four years after the changes. These data indicate a significant decrease in manhours spent per drawing produced following the initiation of the newly developed planning, scheduling, and control system.

II. CONCLUSIONS

Since it is impossible to separate the effect of a single activity from the total situation, it cannot be concluded that the planning, scheduling, and control system described in Chapter III, Page 22, is entirely responsible for the efficiency gains of the Section. It does seem logical, however, to conclude that the system contributes significantly because it is such an integral part of the Section activities. Too, there are certain elements of the situation which seem to have been improved and which might be expected to produce an increase in efficiency. These improvements include: planning, scheduling, control, coordination, communications, job investigation, and job knowledge.

Planning

Planning of design work has progressed from a condition of no formalized planning to a formalized procedure. The new planning technique used has received wide publicity as an efficient planning tool. It would seem that a procedure which requires job planning by acceptable methods would be an improvement over a procedure that required none.

Scheduling

The new procedure for scheduling is much more comprehensive than the one previously used. It can generate one week or one hundred weeks of schedules as required. It can consider all jobs and all resources, and determine the extended schedules of work. It permits looking at the work schedule in considerably more depth than the previously used system.

Also, the establishment of job priorities makes improvements in scheduling possible. It allows jobs to be scheduled a sufficient length of time to complete, thus eliminating interruptions of work in progress.

Control

The new procedure is an improvement over the old in that it provides for a routine control procedure. The weekly review procedure requires the section head to check the status of every job on a periodic basis. It allows the section head to ascertain the status of all jobs and to take corrective action as required.

Coordination

Improved coordination is effected by advance planning for use of resources. The Critical Path Method of planning establishes the interrelation-

ships of tasks to be completed and allows the scheduling of resources required at the appropriate time.

Communication

The new system communicates more information to individuals of the section. In addition to providing a weekly schedule, it gives each person a list of all tasks assigned, including those not scheduled. The relative importance of jobs is indicated to individuals by the rank order listing. It is expected that the most important work be considered first and that an effort be applied to other work in order of importance. Should the individual complete a schedule earlier than anticipated, it is expected that he would proceed to the next listed unscheduled job without being told.

Investigation

Joint investigation of the problem seems to have one major advantage in that it allows the participation of the combined thinking and experience of the section head and the engineer. This joint participation would be expected to result in plans of work which would be reasonable and compatible with requirements and that this procedure would increase the likelihood of effort being applied in a more productive manner.

Job Knowledge

Both the new planning and control procedures permit a better understanding of work to be done. Having a written plan of work allows the section head access to reasonable details for all jobs. The review procedure allows an opportunity to be informed on an up-to-date basis as the work progresses.

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APPENDIX

I. WORK MEASUREMENT PRODUCTION REPORT

Table I is essentially one-third of a typical quarterly production report of the General Mechanical Engineering Department derived from time card data. All personnel—draftsmen, engineers, and supervision—are included and identified by code number. Total time of the individual and the department total time is distributed in accordance with the following classifications:

<u>Symbol</u>	<u>Classification</u>
GT	Gross time spent during the quarter.
ABS	Hours absent from work, such as vacation, sick time, etc.
N	Time of draftsmen spent doing things other than drafting; for example, startup and testing, design.
R	Hours spent making revisions to drawings.
DT	Hours spent making new drawings.
ET	Hours spent doing engineering.
O	Hours spent other than DT, ET, N, and ABS, such as supervision.
HI	Hours spent on incompleted drawings.
HCD	Hours spent on completed drawings

Table II continues the above report. This portion indicates the number of A through F-size drawings completed by each individual and by the total department during the period. Sizes are indicated in the following schedule:

TABLE I

PRODUCTION SUMMARY OF THE GENERAL MECHANICAL ENGINEERING
DEPARTMENT - TIME DISTRIBUTION
(FIRST QUARTER 1965)

Code Number	Time Distribution								
	GT	ABS	N	R	DT	ET	O	HI	HCD
1								142	
2								404	
3	511	16				495			
4	512	137	363		12			8	12
5	511	48	407		56			72	40
6	511	24	97	140	250			670	359
7	511	88				423			
8	511	122	153	114	122			215	173
9								105	
10	512	16				496			
11	511	48				463			
12	510	61	89	132	228			352	148
13	511	16				494	1		
14	511	16				301	495		
15	481	16				464	1		
16	512	24	5	78	405			234	429
17	512	195				317			
18	512	16				495	1		
19								164	
20	511	33				471	7		
21	511	56				451	4		
22	511	67	203	38	203			177	293
23	511	32	435		44			8	40
24	511	36	141	32	302			486	182
25	512	28				484			
26	511	27	222	16	246			173	368
27	511	66	251	88	106			151	161
28	511	16	96		399			203	228
29	514	19	332	82	81			190	131
30	511	16	200		295			263	382
31	511	20				462	29		

TABLE I (CONTINUED)

Code Number	Time Distribution								
	GT	ABS	N	R	DT	ET	O	HI	HCD
32	511	24	48	24	415			533	232
33								78	
34	168	16	16		136			490	
35								256	
36	511	24	64	40	383			423	1284
37	553	24				512	17		
38								8	
39								292	
40								665	
Total	GT 15518	ABS 1347	N 3122	R 784	DT 3683	ET 6027	O 555	HI 6762	HCD 4462

TABLE II

PRODUCTION SUMMARY OF THE GENERAL MECHANICAL ENGINEERING
DEPARTMENT - COMPLETED DRAWINGS
(FIRST QUARTER 1965)

Code Number	Completed Drawings						TDC
	A	B	C	D	E	F	
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	1.0	0.0	1.0
5	0.0	0.0	0.0	0.0	1.5	0.0	1.5
6	0.0	0.0	0.0	0.0	16.0	0.0	16.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	12.1	0.0	12.1
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	1.0	8.0	0.0	9.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	4.0	2.0	11.0	0.0	17.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	1.0	0.0	1.0	8.0	0.0	10.0
23	1.0	0.0	1.0	2.5	0.0	0.0	4.5
24	0.0	0.0	0.0	3.0	6.5	0.0	9.5
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	10.0	0.0	10.0
27	0.0	0.0	0.0	3.0	8.0	0.0	11.0
28	0.0	0.0	1.0	7.5	5.0	0.0	13.5
29	0.0	0.0	0.0	1.0	11.0	0.0	12.0
30	0.0	0.0	3.0	6.0	10.0	0.0	19.0
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE II (CONTINUED)

Code Number	Completed Drawings						TDC
	A	B	C	D	E	F	
32	0.0	0.0	0.0	2.0	7.0	0.0	9.0
33	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.0	0.0	0.0	2.0	37.0	0.0	39.0
37	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	A	B	C	D	E	F	TDC
	1.0	1.0	9.0	31.0	152.1	0.0	194.1

<u>Symbol</u>	<u>Classification</u>
A	A standard size drawing approximately 8 1/2 x 11".
B	A standard size drawing approximately 11 x 17".
C	A standard size drawing approximately 17 x 22".
D	A standard size drawing approximately 22 x 34".
E	A standard size drawing approximately 34 x 44".
F	Any drawing larger than an "E" size.
TDC	Total drawings completed. $TDC = A + B + C + D + E + F$.

Table III contains equivalent production indicators calculated from the data contained in Tables I and II. These factors represent an attempt to reduce all time spent and all production data to a common basis, i.e., hours spent per equivalent E-size drawing. From these, equivalent total production is calculated and listed at the conclusion of the table. The required computations are as follows:

<u>Symbol</u>	<u>Identification and Formula</u>
TEE	Total equivalent E-size drawings—a concept utilized to convert all drawing production to a standard base unit, i.e., E size: $TEE = \frac{A + 2B + 4C + 8D + 16E + 20F}{16}$
EER	Equivalent E-size drawings produced making revisions to the drawings:

$$EER = \frac{R}{AHE} \cdot$$

EEN Equivalent E-size drawings produced by nondrawing time:

$$EEN = \frac{N}{AHE} \cdot$$

TP Total production:

$$TEE + EER + EEN = TP.$$

AHE Average hours spent per E-size drawing.

TED Total equivalent drawings produced:

$$TED = TEE + EER + HI/AHE.$$

DA Drawing average time per E-size drawing:

$$DA = \frac{HCD + R}{TED} \cdot$$

EA Engineering average time per E-size drawing:

$$EA = \frac{ET}{TED} \cdot$$

NDA Nondrawing average time per E-size drawing:

$$NDA = \frac{N + O + ABS}{TED} \cdot$$

DTA Average total hours spent per E-size drawing:

$$DTA = DA + EA + NDA.$$

TABLE III

PRODUCTION SUMMARY OF THE GENERAL MECHANICAL ENGINEERING
DEPARTMENT - EQUIVALENT PRODUCTION
(FIRST QUARTER 1965)

Code Number	Equivalent Production					
	TEE	EER	EEN	TP	AHE	TED
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
4	1.0	0.0	30.3	31.3	12.0	1.0
5	1.5	0.0	15.2	16.7	26.7	
6	16.0	6.3	4.3	26.6	22.4	22.3
7	0.0	0.0	0.0	0.0	0.0	0.0
8	12.1	8.0	10.7	30.8	14.3	20.1
9	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0
12	8.5	7.6	5.1	21.2	17.4	
13	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0
16	13.0	2.4	0.2	15.6	33.0	
17	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	8.6	1.1	6.0	15.7	34.1	9.7
23	1.6	0.0	17.4	19.0	25.0	
24	8.0	1.4	6.2	15.6	22.8	
25	0.0	0.0	0.0	0.0	0.0	0.0
26	10.0	0.4	6.0	16.4	36.8	10.4
27	9.5	5.2	14.9	29.6	16.9	
28	9.0	0.0	3.8	12.8	25.3	
29	11.5	7.2	29.1	47.8	11.4	18.7
30	13.8	0.0	7.2	21.0	27.7	
31	0.0	0.0	0.0	0.0	0.0	0.0

TABLE III (CONTINUED)

Code Number	Equivalent Production					TED
	TEE	EER	EEN	TP	AHE	
32	8.0	0.8	1.7	10.5	29.0	
33	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.0	0.0	0.0
36	38.0	1.2	1.9	41.1	33.8	
37	0.0	0.0	0.0	0.0	0.0	0.0
38	0.0	0.0	0.0	0.0	0.0	0.0
39	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0
						211.5
	DA 24.8	EA 28.5	NDA 23.7	DTA 77.0		82.2

TABLE IV

SUMMARY PRODUCTION REPORT - AVERAGE
DRAWING TIME

1961				
<u>TED</u>	<u>THC</u>	<u>R</u>	<u>DA</u>	<u>Per Cent of 1961 Rate</u>
250.9	5,104	-	22.9	100
1962				
<u>TED</u>	<u>THC</u>	<u>R</u>	<u>DA</u>	<u>Per Cent of 1961 Rate</u>
304.9	5,935	1,072	23.0	100
1963				
<u>TED</u>	<u>THC</u>	<u>R</u>	<u>DA</u>	<u>Per Cent of 1961 Rate</u>
316.7	6,616	1,048	24.2	106
1964				
<u>TED</u>	<u>THC</u>	<u>R</u>	<u>DA</u>	<u>Per Cent of 1961 Rate</u>
277.7	4,798	1,505	22.7	99
1965				
<u>TED</u>	<u>THC</u>	<u>R</u>	<u>DA</u>	<u>Per Cent of 1961 Rate</u>
265.5	4,252	1,257	20.7	90

TABLE V

SUMMARY PRODUCTION REPORT - AVERAGE
ENGINEERING TIME

1961		
<u>ET</u>	<u>EA</u>	<u>Per Cent of 1961 Rate</u>
8,908	35.5	100
1962		
<u>ET</u>	<u>EA</u>	<u>Per Cent of 1961 Rate</u>
5,729	18.8	53
1963		
<u>ET</u>	<u>EA</u>	<u>Per Cent of 1961 Rate</u>
5,924	18.7	53
1964		
<u>ET</u>	<u>EA</u>	<u>Per Cent of 1961 Rate</u>
6,226	22.4	63
1965		
<u>ET</u>	<u>EA</u>	<u>Per Cent of 1961 Rate</u>
4,572	17.2	48

TABLE VI

SUMMARY PRODUCTION REPORT - AVERAGE
NONENGINEERING, NONDRAWING TIME

1961		
<u>N + O + ABS</u>	<u>NDA</u>	<u>Per Cent of 1961 Rate</u>
11,077	44.1	100
1962		
<u>N + O + ABS</u>	<u>NDA</u>	<u>Per Cent of 1961 Rate</u>
9,842	32.3	73
1963		
<u>N + O + ABS</u>	<u>NDA</u>	<u>Per Cent of 1961 Rate</u>
10,967	34.6	78
1964		
<u>N + O + ABS</u>	<u>NDA</u>	<u>Per Cent of 1961 Rate</u>
10,473	37.7	85
1965		
<u>N + O + ABS</u>	<u>NDA</u>	<u>Per Cent of 1961 Rate</u>
11,412	43.0	98

TABLE VII

SUMMARY PRODUCTION REPORT - AVERAGE
TOTAL TIME

1961	
<u>DTA</u>	<u>Per Cent of 1961 Rate</u>
102.5	100
1962	
<u>DTA</u>	<u>Per Cent of 1961 Rate</u>
69.9	68
1963	
<u>DTA</u>	<u>Per Cent of 1961 Rate</u>
77.5	76
1964	
<u>DTA</u>	<u>Per Cent of 1961 Rate</u>
82.8	81
1965	
<u>DTA</u>	<u>Per Cent of 1961 Rate</u>
80.9	79