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Production scheduling

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MANAGEMENT ADVISORY SERVICES
TECHNICAL STUDY 9

Production Scheduling

AICPA

American Institute of
Certified Public Accountants

MANAGEMENT ADVISORY SERVICES TECHNICAL STUDY 9

Production Scheduling

Prepared by the
Management Advisory Services Committee on Technical Studies
of the American Institute of Certified Public Accountants

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Management Advisory Services Technical Studies are intended to be used as instructional matter. This study was prepared under the supervision of the Management Advisory Services Committee on Technical Studies.

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Preface

The scheduling and control of production is obviously a vital activity in any business—without it no company can function. Moreover, the adequacy of the scheduling system has a greater effect on costs than many realize. An inadequate or inappropriate system can seriously harm the competitiveness of an enterprise.

In spite of this, many senior managers have an incomplete knowledge of the production scheduling function. This is often particularly true of executives who have reached their positions by a route that has given them little exposure to production problems. It is equally true of a great many small businesses in which the scheduling job is done by one man, using intuitive judgment rather than a formal system. These situations are frequent sources of sudden problems—the complexity of the scheduling task finally becomes too great for intuition to handle, or the scheduler leaves or retires. Occasionally in much larger organizations, where a complex and sophisticated system is used, senior executives may be unwilling to grapple with its complexities and unable to see the simple basic principles underlying it. Finally, many people—perhaps the majority—are unaware that the basic principles of production scheduling are as applicable to a service company as to a manufacturing plant.

The CPA can be of invaluable help to his clients in such cases. Although he is not expected to be an expert in the production scheduling field, he is an expert in quantitative methods, the processing of complex data, and the measurement and analysis of costs. Therefore, given a knowledge of basic scheduling principles, he will be able to analyze situations and define problems, either to identify areas of inefficiency and high cost, or to point out possible pitfalls. His ability to bring a fresh viewpoint, devoid of personality problems and habitual attachment to present methods, coupled with his overall knowledge of company dynamics, will permit him to make a unique contribution.

Introduction

Before undertaking any complex task, it is necessary to decide how to go about it. This is the whole purpose of production scheduling: to determine the best method of performing a given task, and to see that it is actually performed that way.

If the task is simple, it can be scheduled in one's mind. If a person has four telephone calls to make, he can decide when and in what order to make them without any need for a formalized system. Many small manufacturing operations are scheduled in this way. However, the more complex the operation, the more systematic and formalized the system for scheduling must be. Large and complex situations (a large automobile plant, for example) require much more sophisticated scheduling than human minds can provide, and complicated computerized systems must be used. Even these, however, use the same basic principles as the one-man shop whose schedule is entirely in the operator's head.

The bulk of this study will discuss production scheduling in terms of a machine shop making parts for assembly into final products. Production scheduling is equally applicable to office work, department stores, chemical plants, and many other organizations. However, a large machine shop is often one of the more difficult businesses to schedule. Consider, for example, the task of planning to make available, at the proper place and time, the quarter of a million parts needed to assemble an aircraft, with each part requiring anything from ten to 50 operations to make it. The principles discussed here for relatively complex scheduling can be applied to virtually any other scheduling situation merely by simplifying them and eliminating those which do not apply.

It is not possible to determine an efficient schedule without a clear idea of what is to be produced and what resources are available to produce it. Therefore, the first chapter of this book deals with these essential preliminaries. The second chapter discusses the basic principles of scheduling. Later chapters discuss more complex and varied situations as well as the more sophisticated tools available for handling them.

The reader should be warned that there is no consistent terminology in the production scheduling field. Production scheduling itself is often called "production control"; although others use the term "control" to describe only the feedback part of the scheduling system. The production scheduling department is called, most frequently, the "production department," even though this is misleading. Other names are "production control department", "production planning department," and so on. Therefore, the reader should understand that in any discussion of production scheduling, familiar terms may be used with unfamiliar applications.

1

Specifications, Routing, and Capacity

Product Specifications

Production scheduling basically determines the "what, how, where, and when" of making a product—what will be made (the product specification), how and where it will be made (routing), and when each stage of its manufacture will be performed (scheduling).

The need for a product specification is obvious. Until we decide what is to be made, we cannot decide how to make it, or how long the necessary steps will take. It also follows that unless the product is specified exactly, the method and time required to make it cannot be measured, and the schedule cannot be efficient. Many problems that are blamed on a poor scheduling system have proved to be nothing more than the result of inadequate product specification.

Blueprints

The traditional way of describing a manufactured product exactly is by an engineering drawing or "blueprint."[1] A blueprint of a simple part is shown in Figure 1 on page 4. The blueprint has many advantages: it can carry a great deal of information (surface finishes, tolerances, required materials, etc., can be specified in addition to dimensions), and it is frequently a single sheet of paper that can be copied easily.

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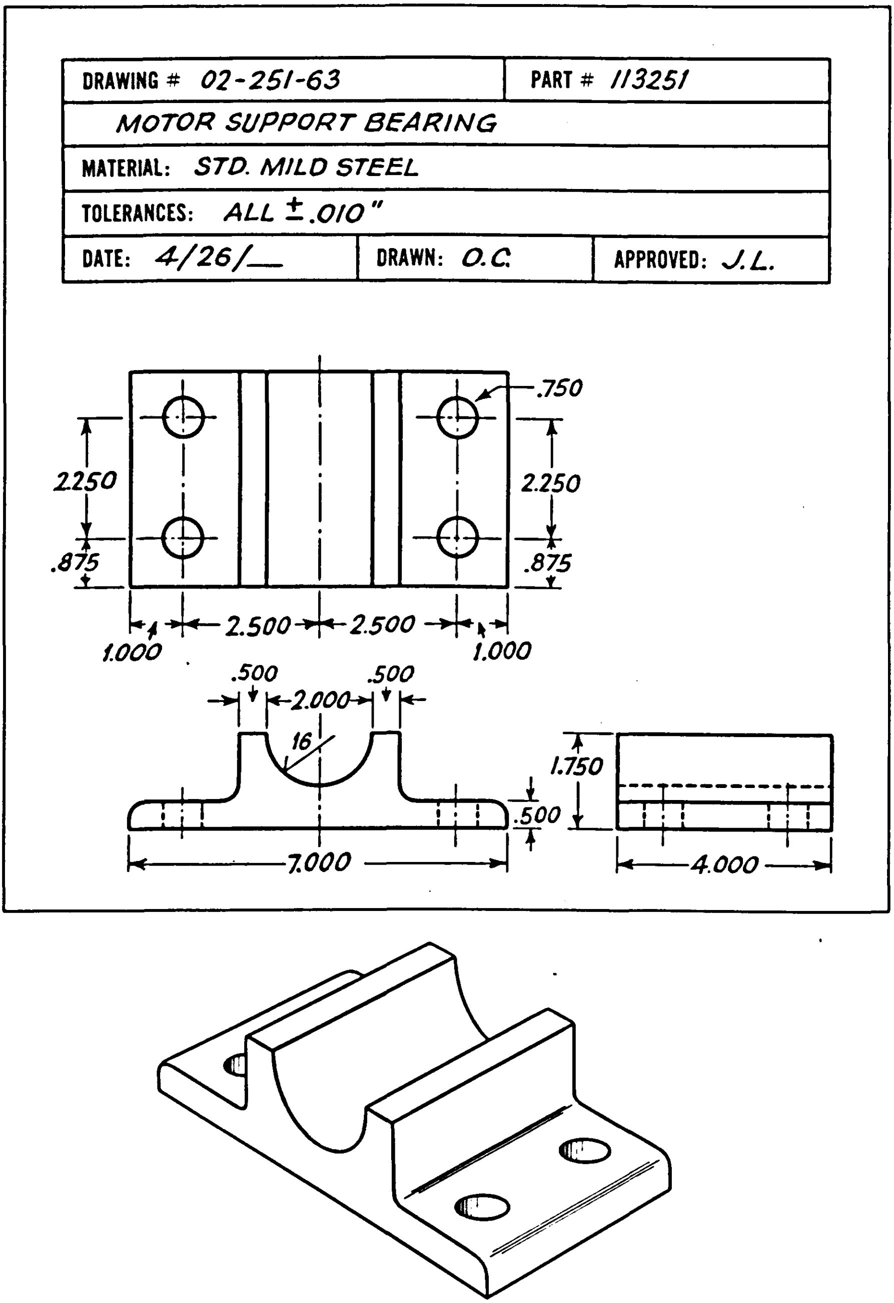
[1] A term that originated in the early days of engineering when these working drawings were reproduced by a process that gave white lines on a blue background. This process is now obsolete, but the name persists.

FIGURE 1 **Example of Engineering Drawing**



DRAWING # 02-251-63		PART # 113251
MOTOR SUPPORT BEARING		
MATERIAL: STD. MILD STEEL		
TOLERANCES: ALL ±.010"		
DATE: 4/26/__	DRAWN: O.C.	APPROVED: J.L.

Parts and Sub-Assembly Lists

The blueprint has certain limitations, the most serious of which is that it cannot handle much complexity. It is clearly impossible to describe a complete automobile, much less an aircraft, with a blueprint. It is true that each individual part can be described, but since an automobile incorporates several thousand different parts, its blueprints would comprise an unmanageable set of large volumes. Consequently, complex products are more usually specified by a list of the parts that compose them. An example of a parts list, (also called a "bill of materials," "materials list," or "requirements list") is shown in Figure 2 on page 6. Still more complex products may be described as an assembly, not of individual parts, but of assemblies of parts, called sub-assemblies. Each sub-assembly is then described by a parts list, or possibly by a list of smaller sub-assemblies.

To reduce the volume of required paperwork, most operations of this complexity use a coding system. Each sub-assembly and each part is specified by a code number, rather than a full description. Ideally, a code number itself should provide useful information to the reader (whether this be a man or a computer). For example, in the code number 2774630, the first two digits might specify the material of which it is made; the second two, the basic nature of the item (such as a screw); and the last three, the details of the item (such as: ¼" diameter, 1" long, countersunk).

Classification systems based on other criteria such as end-use or storage location are also used, but the systems that "describe" the product are generally simpler and more flexible.

Thus, the most common forms of product specification are blueprints or parts lists, or both. However, any type of description which is complete and understandable is appropriate. The information which these specifications convey is usually some or all of the following:

1. The detailed listing of parts and components which go into the final product.
2. A pictorial representation of the product.
3. Names and code numbers of the product and each of its parts.
4. The materials used and surface finish.
5. Tolerances, quality, and reliability requirements.
6. Testing methods to be used.
7. Type and amount of packaging required.

FIGURE 2 Example of Parts List

PARTS LIST

Item #79643851 Item Description: Rear Drum Brake

Application: 2213852 2243852 2303852

Quantity	Part #	Description
1	79732 P	Brake Backplate—10″
1	79215 P	Brake Drum—10″
2	79318 P	Brake Shoe M
2	79518 P	Brake Lining 2 x 10
1	79032 P	Brake Cylinder—Rear
2	79633 P	Pistons—Rear
2	79634 P	Piston Seals
1	79402 P	Brake Adjuster
1	79635 P	Brake Hose Connector
2	79273 P	Brake Return Spring
1	79636 P	Bleed Valve Screw
1	79806 P	¼″ Adjusting Nut
4	79815 P	½″ Csk Screw
16	79880 P	3/16″ Hollow Rivet

Control of Product Specifications

An important element of the scheduling system is the method used to distribute and control product specifications (blueprints, parts lists, etc.). At first sight, this problem may appear simple: it should be met by merely producing the necessary number of copies and distributing them to all interested parties.

However, the solution is rarely that simple. One problem is the large numbers of specifications, which are bulky to store and time-consuming to sort. In such a situation there is the danger that through carelessness the wrong specification may be referred to.

Another frequent problem is that of excess information. Operators often receive more information than they need to perform a particular task. They may in fact receive information that management would prefer that they not know. One method of overcoming this problem is by the use of a duplicator. Many duplicators are capable of selecting certain parts of the master specification for reproduction and of omitting others. Thus, although a single master is prepared containing all the required information, careful forms design makes it possible to reproduce only the portions of this information that are required at *each* work location. An example is shown in Figure 3 on pages 8 and 9. If specifications are stored in a computer, the required instructions may easily be programmed to provide information selectively.

The most serious problem arises when specifications are changed. It must be possible to ensure that the same change is made in the records of each person holding a specification. The problem may be even more difficult if the change is made while batches of the product are in various stages of manufacture. It may be possible to issue the new specification to Department *A* immediately. However, if it is also issued simultaneously to Department *B*, that department may subsequently receive units of the product from Department *A* that were started under the old specification and for which the new processing specification is inappropriate. In such a case, the new specification should not be issued to Department *B* until all units produced by Department *A* under the old specification have been completed.

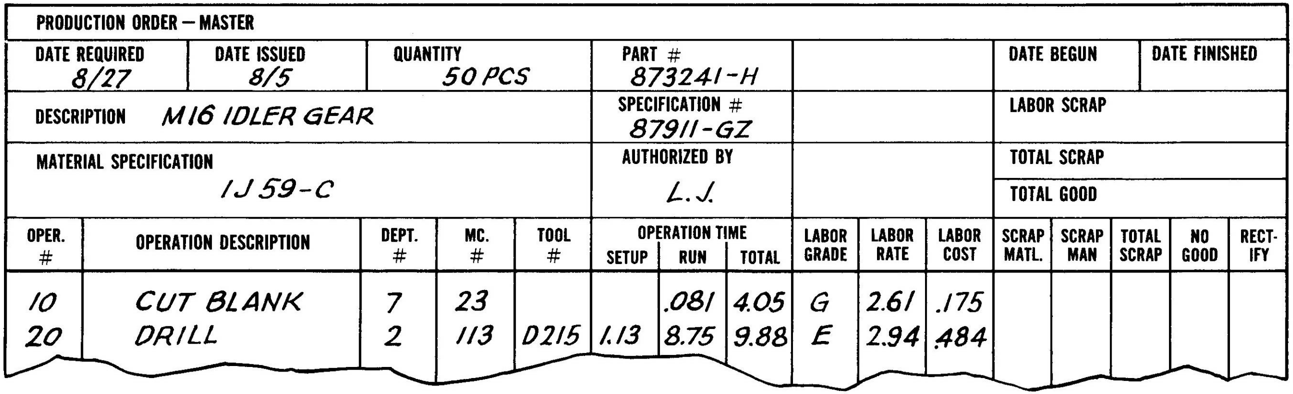
Many plant personnel tend to build up "personal libraries" of specifications and related material at their work stations. This practice heightens the danger that an out-of-date specification may be used. The best way to avoid this is to expressly forbid such personal files.

Yet another problem arises in changing the specification of a part or sub-assembly which is used in a variety of final assemblies. It is a difficult but essential task to ensure that the specifications of *all* final assemblies using the part are altered to conform with the change. This is one reason why specifications are often stored in a computer, which can rapidly sort through all parts lists to identify the products involved. In some cases, the computer may even be programmed to make the necessary changes automatically.

This rigorous control of the distribution of specifications and specification changes is as important as the specifications themselves. The method used will depend on the particular situation. One basically simple method is to attach the specification to the product, so that the two travel together throughout the operations. This is simple and effective provided the production system is not too complex, the specification carries no confidential information, and, most important, the specification is attached in such a way that it cannot be separated from the product and lost.

FIGURE 3. **Selective Duplication of Production Order**

MASTER COPY

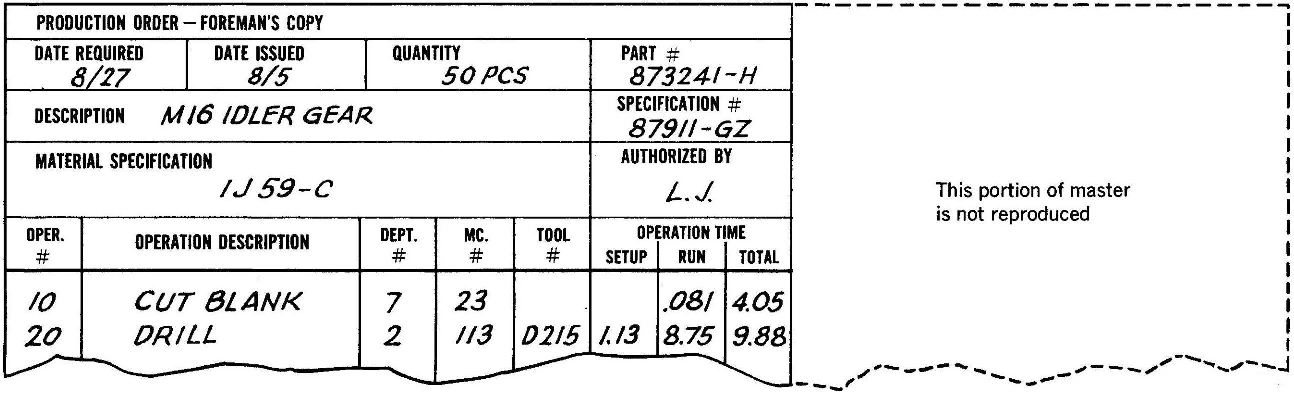


PRODUCTION ORDER — MASTER

DATE REQUIRED 8/27	DATE ISSUED 8/5	QUANTITY 50 PCS	PART # 873241-H		DATE BEGUN	DATE FINISHED
DESCRIPTION M16 IDLER GEAR			SPECIFICATION # 87911-GZ		LABOR SCRAP	
MATERIAL SPECIFICATION 1J 59-C			AUTHORIZED BY L.J.		TOTAL SCRAP TOTAL GOOD	

OPER. #	OPERATION DESCRIPTION	DEPT. #	MC. #	TOOL #	OPERATION TIME SETUP	OPERATION TIME RUN	OPERATION TIME TOTAL	LABOR GRADE	LABOR RATE	LABOR COST	SCRAP MATL.	SCRAP MAN	TOTAL SCRAP	NO GOOD	RECT-IFY
10	CUT BLANK	7	23			.081	4.05	G	2.61	.175					
20	DRILL	2	113	D215	1.13	8.75	9.88	E	2.94	.484					

FOREMAN'S COPY



PRODUCTION ORDER — FOREMAN'S COPY

DATE REQUIRED 8/27	DATE ISSUED 8/5	QUANTITY 50 PCS	PART # 873241-H
DESCRIPTION M16 IDLER GEAR			SPECIFICATION # 87911-GZ
MATERIAL SPECIFICATION 1J 59-C			AUTHORIZED BY L.J.

OPER. #	OPERATION DESCRIPTION	DEPT. #	MC. #	TOOL #	OPERATION TIME SETUP	OPERATION TIME RUN	OPERATION TIME TOTAL
10	CUT BLANK	7	23			.081	4.05
20	DRILL	2	113	D215	1.13	8.75	9.88

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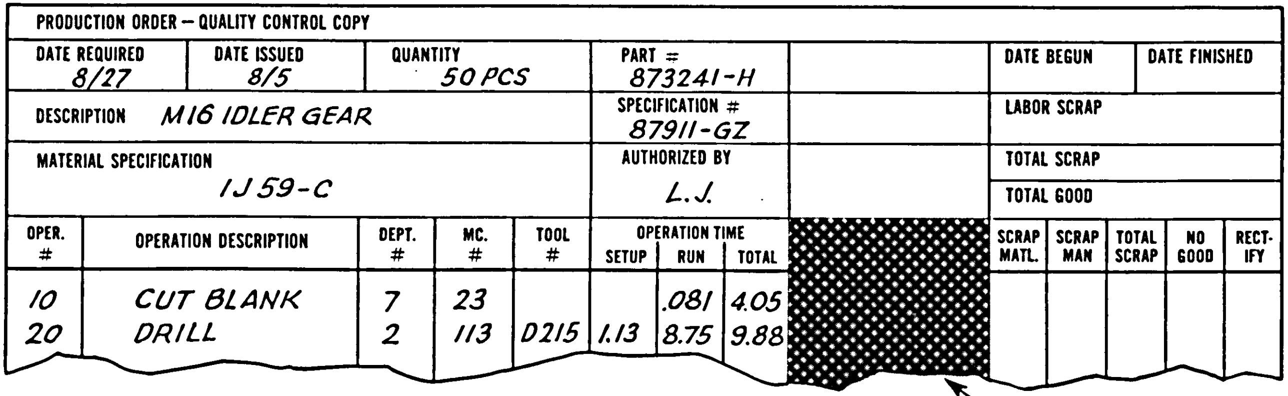
QUALITY CONTROL COPY

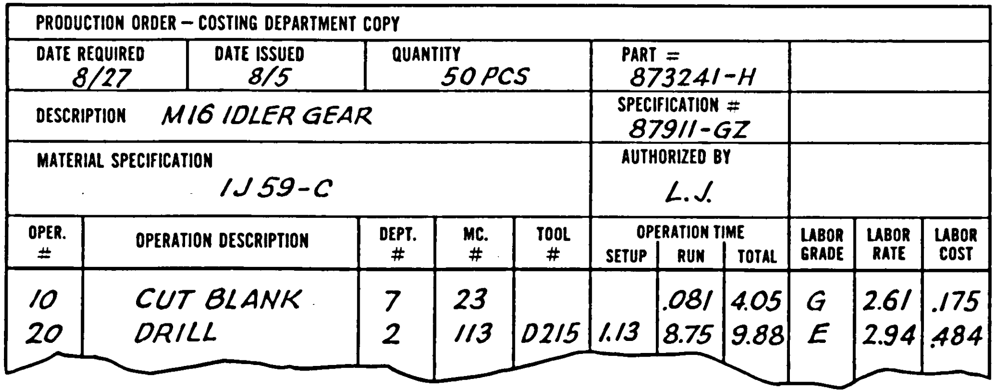


PRODUCTION ORDER — QUALITY CONTROL COPY

DATE REQUIRED 8/27	DATE ISSUED 8/5	QUANTITY 50 PCS	PART # 873241-H		DATE BEGUN	DATE FINISHED
DESCRIPTION M16 IDLER GEAR			SPECIFICATION # 87911-GZ		LABOR SCRAP	
MATERIAL SPECIFICATION 1J59-C			AUTHORIZED BY L.J.		TOTAL SCRAP TOTAL GOOD	

OPER. #	OPERATION DESCRIPTION	DEPT. #	MC. #	TOOL #	OPERATION TIME				SCRAP MATL.	SCRAP MAN	TOTAL SCRAP	NO GOOD	RECT-IFY
					SETUP	RUN	TOTAL	▨					
10	CUT BLANK	7	23			.081	4.05	▨					
20	DRILL	2	113	D215	1.13	8.75	9.88	▨					

COSTING DEPARTMENT COPY



PRODUCTION ORDER — COSTING DEPARTMENT COPY

DATE REQUIRED 8/27	DATE ISSUED 8/5	QUANTITY 50 PCS	PART # 873241-H	
DESCRIPTION M16 IDLER GEAR			SPECIFICATION # 87911-GZ	
MATERIAL SPECIFICATION 1J59-C			AUTHORIZED BY L.J.	

OPER. #	OPERATION DESCRIPTION	DEPT. #	MC. #	TOOL #	OPERATION TIME			LABOR GRADE	LABOR RATE	LABOR COST
					SETUP	RUN	TOTAL			
10	CUT BLANK	7	23			.081	4.05	G	2.61	.175
20	DRILL	2	113	D215	1.13	8.75	9.88	E	2.94	.484

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Some systems place the responsibility for specification control on the foreman. When he assigns each man his task, the foreman is responsible for issuing the appropriate specification, which *must* be returned to him when the job is complete. In turn, the scheduling department can exercise some control over the foreman: i.e., it knows when the first parts under a new specification will reach his department and can issue the new specification to him at that time, requiring him simultaneously to return the old one for destruction. The latter requirement can provide good control over changes.

In complex situations, or those in which specification or schedule changes are frequent, a new specification is often issued *whenever the production of a new unit or batch is begun,* regardless of whether the specification has been changed or not. At the conclusion of each production run, this specification is destroyed or returned to the scheduling department as a signal that the batch has been completed. This increases the amount of paperwork required, but also means that specification changes have to be made only once—on the master specification—and are then automatically reproduced without error.

Sophisticated systems of this kind often store specifications in a computer. This provides rapid, low-cost reproduction and a large storage capacity for specifications. Moreover, a computer can be programmed to change many parameters of a specification—parameters which may change as the result of altering a single input—and to check these resulting specification changes for logic and consistency. Such computer-based systems are very efficient when the same sub-assemblies are used in many different products. The product specification simply contains the sub-assembly code number. The parts list for the sub-assembly is stored elsewhere in the computer and can be selected and printed out by the computer whenever the list is needed for a product specification.

Routing

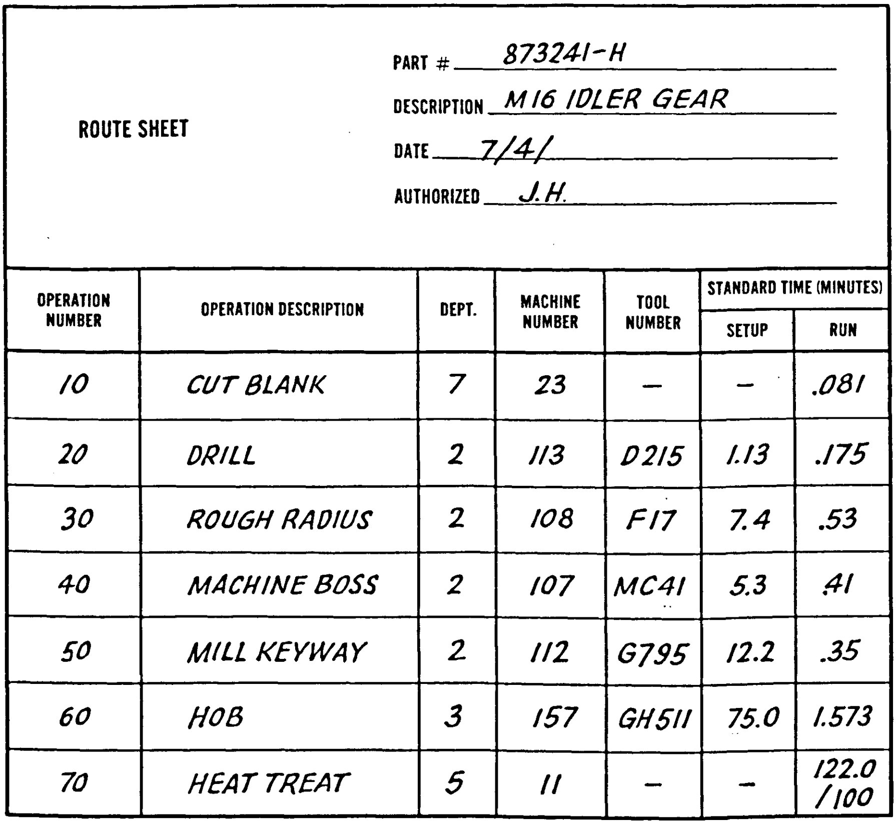
Once the product has been specified, management must decide how it will be made. Deciding what machines will be used to make it, and in what order, is known as routing.

In many small shops, and in some large ones that make only a small number of products, routing is informal. In such cases, either it is obvious from the nature of the product what machines will be used to make it, or a shop superintendent can decide minute-by-minute what machines to use. In more complex cases, a formal system is needed, and the basis of this system is the route sheet.

Route Sheets

A route sheet (also called a "process sheet," "layout," or "operation list") is simply a sequential list of the processes that the product will go through. An example of a simple route sheet is given in Figure 4 below. It describes the steps in making an idler gear and specifies the department, machine, and tool which will be used for each step.

FIGURE 4 **Route Sheet**



ROUTE SHEET

PART # 873241-H
DESCRIPTION M16 IDLER GEAR
DATE 7/4/
AUTHORIZED J.H.

OPERATION NUMBER	OPERATION DESCRIPTION	DEPT.	MACHINE NUMBER	TOOL NUMBER	STANDARD TIME (MINUTES)	
					SETUP	RUN
10	CUT BLANK	7	23	–	–	.081
20	DRILL	2	113	D215	1.13	.175
30	ROUGH RADIUS	2	108	F17	7.4	.53
40	MACHINE BOSS	2	107	MC41	5.3	.41
50	MILL KEYWAY	2	112	G795	12.2	.35
60	HOB	3	157	GH511	75.0	1.573
70	HEAT TREAT	5	11	–	–	122.0 /100

This particular route sheet applies to the simple situation in which the idler gears are always made on the same machines in exactly the same way. In practice this happens only when no alternative routing is possible, as in the case of a single production-line setup for the manufacture of the idler gear. More commonly, a variety of routes are possible, and in some instances it is possible to vary the sequence of operations.

Why should production management want to follow any other routing than the one in Figure 4, since, other things being equal, it should be the most efficient routing possible? The answer is that other things are *not* usually equal. Operations may change according to conditions in the plant. These conditions might include the work flow pattern, machine capacities, and existing machine loads. For example, Milling Machine Number 112 may have a week's backlog of work; whereas, an idle broach may be used for the same job. Therefore, to meet a deadline, it may be better to use the broach for operation number 50.

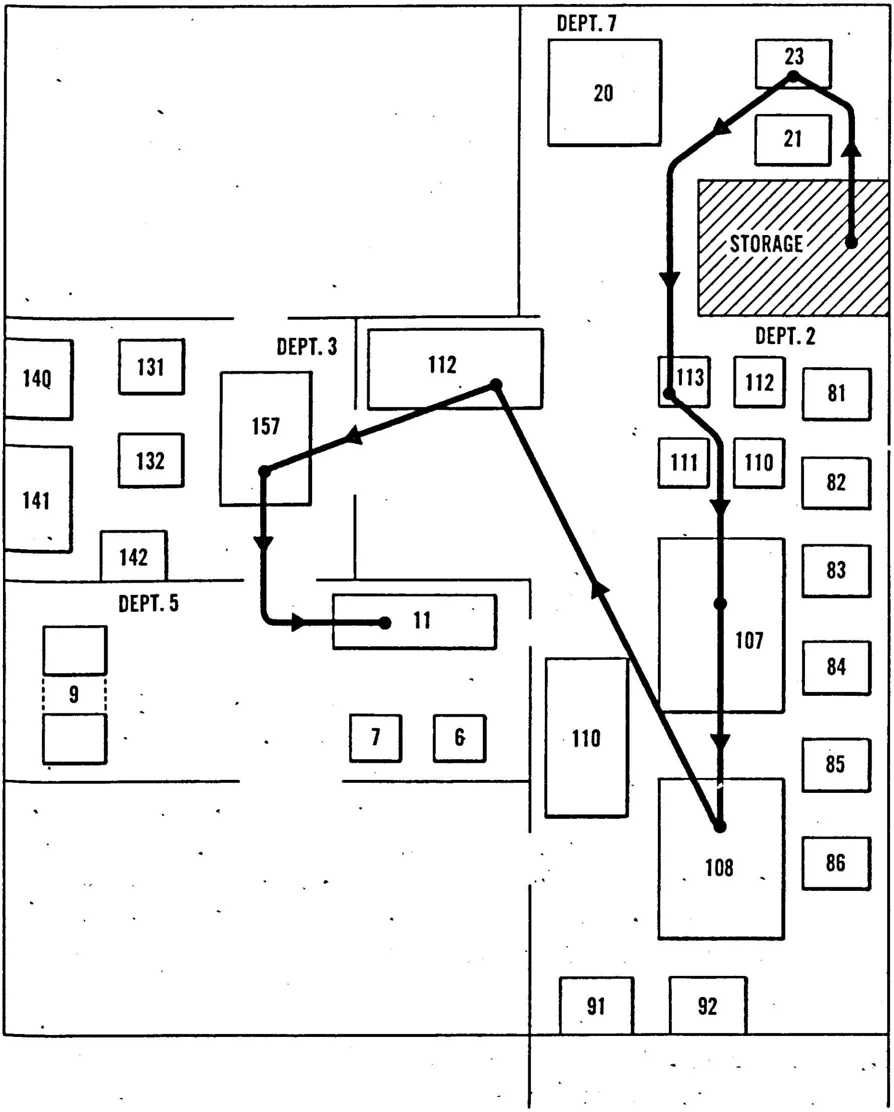
Work Flow

Efficient routing will optimize the distance a product must be moved, the number of moves required, and the direction of movement in order to minimize delays and materials handling costs. The simplest way of visualizing the flow of the product is by a flow diagram. This is simply a map of the plant on which the path the product will follow is drawn. Figure 5 on page 13 shows a flow diagram for the idler gear used in the previous example (Figure 4, page 11).

A variant of the flow diagram is the "string" diagram. In a string diagram, instead of drawing lines between machines, the methods engineer sticks pins in the plant layout plan at each machine location and then joins these pins with thread along the path to be followed by the product. The effect of changes in the flow pattern can then be checked by simply moving the thread, without the need to redraw the new flow and erase the old.

Thus the flow of work specified by the production scheduling department will have an effect on the efficiency of production, and while flow diagrams will probably not be drawn for every product in every case, they should be kept in mind as an important scheduling aid. They have the added advantage that they often illustrate faults in the layout of the plant, and correction of these faults may significantly improve general plant efficiency.

FIGURE 5 Flow Diagram



Capacity

It has already been suggested that the backlog of work placed on production equipment will influence routing decisions. Ideally, material should be routed in such a way that it not only follows an efficient flow through the plant, but also that all machines are kept busy to the limit of their capacity. This is rarely possible in practice, and a compromise must be reached among these and other criteria. But a knowledge of the capacities of machines and how to load them is a key part of the scheduling job.

Machine capacities are always expressed in terms of time—so many pieces per minute, or so many hundred pieces per hour. The time will naturally vary with each different piece, but for any one piece there should be a fixed time for the work done on it by a particular machine. This is called the "standard time" for the job. Its measurement is usually the responsibility of time standards specialists who normally arrive at an average time per piece, either by timing the actual job over many cycles with a stopwatch or by deriving it from tables that provide a standard time for each element of the job. Usually an *average* time is sufficiently accurate for scheduling purposes, though in a few cases (assembly of complex components, for example), a probability distribution of the time required may be needed.

No machine, at least in the long run, works 100 percent of the time. Therefore, various allowances for operator breaks, machine adjustments, maintenance, and so on must be added to the "cycle" time (the time taken to process one part). As a result, a list of standard times is produced for every part on every machine[2], and a list of machine capacities (i.e., so many parts per shift) is developed for each part.

There is one more factor that must be considered before it is possible to load a machine accurately, and that is setup time. Whenever a machine begins work on a different part, adjustments must be made, tools changed, and so on. This may take several minutes or several days, but the schedule will not work if this setup time is ignored. Thus, a second set of standard times must be developed for each part on each machine to reflect the time needed to set the machine up.

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[2] In practice, many plants set standards for only that portion of parts which they make on a regular basis. The remainder are made so infrequently that it is usually more economical to work with a rough estimate of the time required than to develop an accurate standard.

(Note that the route sheet in Figure 4 includes both times for each operation in the last column.) Once this setup time is known, the total time required for a lathe to machine the radius of a batch (or lot) of 100 gear bosses can be determined. If it takes five minutes to set up the lathe for the job, and one minute to machine each boss, the time per lot is as follows:

setup time + (the standard time per part × the number of parts)
or
five minutes + (one minute × 100 pcs.)
or
105 minutes

Such detailed calculations are valuable, but production scheduling is more concerned with aggregate times. Thus the number of products a department can produce in a week is initially more relevant than the number of gear bosses a lathe can machine in an hour. This is often a function of the capacity of a single machine (or group of similar machines). Usually one operation, known as the "bottleneck" operation, limits department output, and the department capacity is therefore assumed to be the same as the capacity of that operation. Where this is not the case, an aggregate department capacity may be calculated from individual machine capabilities or from experience.

Once it is known what is to be made, when it must be finished, the machines available to make it, what the layout is, and how long each machine will take to produce the required output, it would seem that scheduling the products through the plant is merely a matter of common sense. This is perfectly true, and many small plants do operate purely on this basis. However, if the scheduling problem becomes complex, mere common sense breaks down because no one can hold all the information required in his mind at once. Therefore, scheduling systems, ranging from simple control boards to large computer systems have been developed to help, but not to replace, human common sense. These will be described in later sections of this study.

2

Basic Scheduling Procedures

The Master Schedule

Whether a plant is operated to fulfill outstanding customer orders, to replenish stock that is maintained in advance of orders, or to produce against a sales forecast, the eventual customer will largely decide what the plant will make, and when. Regardless of how badly he wants an order, however, a customer cannot be supplied with an item before the production department has the facilities to make it. Therefore, the sales department wants to know *how soon* production can supply a particular item, while the production scheduling department wants to know as soon as possible what the sales department expects to be selling. It is essential, therefore, that these two departments work together in developing a "master schedule" for the plant.

A master schedule is a timetable showing when all orders now on the books will pass through the various production departments. This is where the knowledge of machine capacities must be known. With such knowledge the production scheduling department is able to determine that the orders now on hand will occupy a certain department at a certain time for a given period.

Once scheduling knows the *present* "load" on each department, it can give the sales department delivery dates on *new* orders. When these orders are firmed up, they can be added to the master schedule, thus extending the delivery date for future orders. Of course, as this process goes on, current orders are being shipped, so that at times of stable business the delivery period will normally remain fairly constant.

This process is shown diagrammatically in Figure 6, page 19. The sales forecast (or actual orders on hand) is compared with finished inventory (if any) to determine *net* requirements. Since some of these requirements will be met by work currently in process, this "inventory-in-process" will be subtracted from the net requirements. The result is the additional orders which must be scheduled for production.

A comparison of plant capacity with (1) work in process and (2) the existing master schedule determines what free capacity remains. This free capacity is then filled with the new orders scheduled for production, resulting in a revised master schedule.

The revised master schedule will give a new delivery lead time. This new lead time is reported to the sales department, which in turn uses it in preparing the next sales forecast or in quoting promised delivery dates for new orders.

Releases

The master schedule, on a broad scale, is a "road map" of future production. It does not necessarily give production scheduling the authorization to *begin* work on any items. If the master schedule is based upon a sales forecast, such authority to start production is usually issued by the sales department in the form of "releases," written orders to production scheduling to begin making a given quantity of a given product and to have it completed by a certain date.

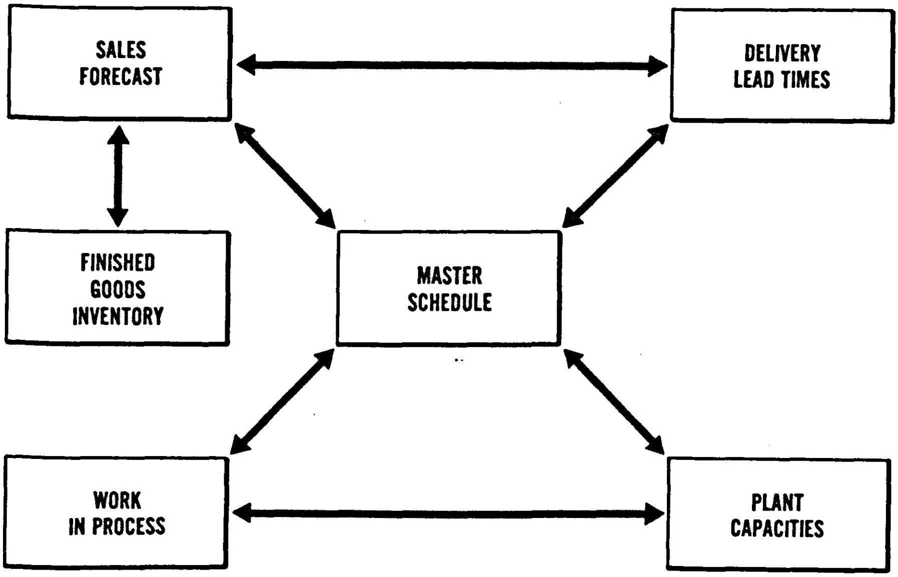
Bill of Materials

When the production scheduling department receives a release order, it "explodes" it into a "bill of materials" or "requirements list." Then, by using the parts list discussed in the previous chapter, production scheduling merely multiplies the number of required parts per item by the number of final products needed (adding a few extra to allow for spoilage, repair parts, etc.), thereby obtaining a listing of the total parts required to fill the order.

Producing the Schedule

Production scheduling also knows how these parts will be made (from their route sheets) and how long each stage of manufacture will take. Therefore, the production scheduler can work backwards from

FIGURE 6 **The Master Schedule**



the *shipping date* to determine when each stage in the manufacture of each part should begin. Such an analysis should go all the way back to the ordering of raw materials if these are not available in inventory. This information, together with the same data for all other products released but not yet completed, constitutes the production schedule.

In developing the production schedule, it is equally acceptable to work forward from the *earliest date* at which raw materials can be made available, through all the processes involved, to the earliest possible shipping date. Many companies prefer to develop their schedules this way. However, when there is no particular advantage in shipping earlier than the promise date, the "working backwards" method offers the advantage of leaving gaps in the schedule. These gaps can then be used to accommodate special "rush" orders, remaking of parts because of faulty workmanship, etc., without the need for extensive rescheduling. The other way, every subsequent job must be pushed back every time an emergency job has to be inserted in the schedule.

Shop Order or Production Release

Once the schedule has been determined, it must be implemented. This is accomplished by issuing appropriate instructions or shop orders to all those involved in carrying out the schedule. Different methods for "production release" are used in different companies, but all methods are directed toward the same objective—to issue complete instructions to the production workers and all others who will carry out the work required. Under most systems, the production release is accomplished by issuing shop orders to the foreman, possibly with planned schedule periods for key operations. The foreman is then responsible for issuing instructions to his men.

The shop order includes instructions about what to make (i.e., specifications, or at least an instruction as to what specifications to use), how many to make, how to make them (routing, operation sheets, special instructions), and when to make them (usually in the form of a deadline for completion of key operations). It may also include a materials and tooling release authorizing the operator to draw the necessary raw materials and tooling from the stores area. If the part is already in process in another department, the foreman will be told when the parts should arrive. Meanwhile, other instructions are issued to other departments, such as requirements for quality control and testing, packing, etc. The whole process is diagrammed in Figure 7, page 21.

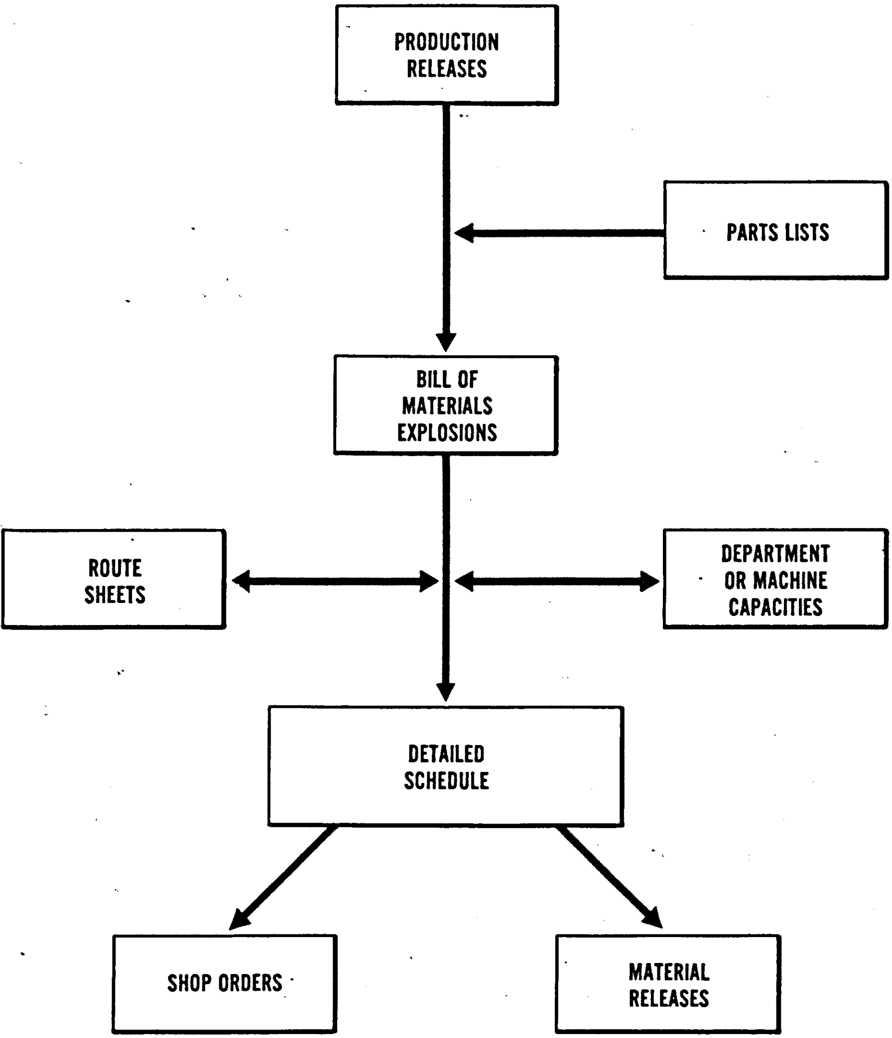
These shop orders are really instructions; the production people must act on them if the system is to work.

Practical Problems

In practice, no schedule works out exactly as it was planned. This is true for a variety of reasons, some of which can be anticipated. For example, there will certainly be some scrap, and past records will indicate roughly how many extra parts (and therefore extra time) should be allowed for this. Machines will sometimes have to be given "time off" for regular or unusual maintenance, and by coordinating with the maintenance department, time can be allotted for this too. The transportation of materials between work stations must be allowed for, and time must be available for inspection and testing activities.

There will also be unforeseen interruptions and delays. "Rush" orders are an example. They arise whenever an order has to be given priority treatment over other orders—frequently because a valuable customer wants something in a hurry. A batch of parts may be spoiled and have to be remade; a machine may break down; or a key operator may be taken ill. Some, if not all, of these things are going to happen, so the scheduler normally gives himself a certain amount of "slack" in

FIGURE 7 **The Detailed Schedule**



his schedule to accommodate them. The amount of slack time varies depending on the type of operations. An average overall slack allowance is often about 5 percent.

No one can predict the more serious interruptions like the breakdown of a key machine or the absence of a key worker. The schedule, therefore, cannot take account of such incidents, since they occur so sporadically. The scheduler can only react to these interruptions once they happen. There are several ways in which this can be done. The simplest, but perhaps least desirable, method is to alter the promise date and tell the customer that his order will be delayed. To avoid such a situation, capacity may be increased by working overtime or using additional workers. Another alternative is the maintenance of in-process inventory to provide a "buffer." Thus, if the drilling machine breaks down for two hours, work can continue if a stock of two-hours worth of drilled parts has previously been built up. Obviously it is too late to make this decision *after* the machine has broken down. Such a policy decision must be made in advance, recognizing the cost involved in storage space, inventory investment, and so on. In practice, these costs prohibit the use of such interim stocks, except in the case of a few critical operations.

Schedule Changes

The most usual way of adjusting for unforeseen problems is to change the schedule. Often it can be rearranged in such a manner that the problem can be accommodated without any critical orders being seriously delayed. The rearrangement of schedules is a continual task of the scheduling department.

It would, of course, be uneconomical to revise the *entire* schedule after every change in the plant situation. Normally the scheduling department attempts to issue a firm schedule for a short period—perhaps one week—and a more tentative schedule for two or three weeks beyond. Ideally the firm part of the schedule is not altered, but at the end of the week, the deviations from it are noted and taken care of by adjusting the following week's schedule, which then becomes firm. The time period chosen, whether a week, a day, or some other, depends on how fast the plant needs to react to changes. If the products take only two weeks from raw material to finished goods, a one-week schedule would be too long: it would not allow sufficient time to react to changes and still meet promise dates. On the other hand, if the throughput time is two months, rescheduling daily would obviously be unnecessary and uneconomical. In many cases, a computer, by eliminating much of the manual rescheduling work, and because of its high speed, can increase the frequency with which a plant can reschedule economically.

Feedback

It becomes obvious that rapid, complete, and accurate feedback on schedule compliance is essential to the scheduling department. A system must be set up to provide this information. Normally such feedback is an extension of the system for issuing work orders, as described earlier. Once a man has completed the job, or at the end of the day, he will return his shop order (or equivalent document) to the man who issued it to him, along with a record of the number of parts completed. This information is returned to the scheduling department to signal the completion, or partial completion, of the job. In addition, at quality control points, inspectors normally report the number of good parts they have inspected and passed on to subsequent operations, and the number of parts they have scrapped. Also the foreman must be responsible for reporting at once to the scheduling department any major dislocation of the schedule such as a serious machine breakdown.

Feedback of this kind is often useful to other departments as well. In many companies, production scheduling is responsible not only for collecting this information, but for passing it along to the payroll department for wage compilations, to the accounting department to determine job costs, and so on.

Expediting

In a large plant the production scheduling system cannot be relied upon to operate successfully alone. After all, it is operated by people, and people are fallible. The greater the number of people involved, the greater the possibility of mistakes. Many large plants therefore employ shop-floor troubleshooters, called "chasers" or "expeditors." It is their responsibility to maintain maximum work flow on the shop floor. They are responsible for following up "rush" and "overdue" orders, shepherding these orders along and seeing that they receive the necessary priority. The expeditors watch for trouble spots, search for lost orders, verify quantities, and frequently make minor schedule changes to keep the system flowing as smoothly as possible. It is important to note, however, that *excessive* numbers of expeditors in a shop are frequently a symptom of a defective scheduling system.

Preventive Maintenance

In any production shop, maintenance could be delayed until a machine breaks down. On the other hand, a program of "preventive maintenance" could be set up in which each item would be overhauled before it might be expected to break down. This is rather like doing repairs "in advance." The big advantage of such preventive maintenance is that maintenance can be done at a *convenient* time. Instead of a machine breaking down in the middle of an urgent production run (as they always seem to do), and possibly holding up the work for other machines as well, it can be overhauled at a time when it would otherwise be idle. Thus no production is lost and no delays caused.

However, *excessive* preventive maintenance can waste a great deal of money by checking and overhauling machinery that is in good condition, and such a program will still not entirely eliminate breakdowns. A middle course is desirable. We should attempt to schedule maintenance on a machine before it breaks down, while recognizing that some breakdowns will *still* occur. As a rule of thumb, many manufacturing companies conclude that if the maintenance men spend around 25 percent of their time fixing breakdowns and 75 percent on preventive maintenance, they have the proper balance. It is dangerous, of course, to apply that sort of average across the board. For instance, a 25 percent figure would be far too high a percentage of breakdown work for an automobile production line, whose downtime costs thousands of dollars a minute, but might be too low for other less automated companies.

Usually preventive maintenance is provided on some sort of a schedule. This is a different kind of schedule from that used by production; it usually involves how often certain maintenance jobs should be performed on certain machines. For example, a machine may need inspection once a week, adjustment and lubrication once a month, and a major overhaul once a year.

If preventive maintenance can be done outside of machine running time, such as at night, on weekends, during the operator's lunch time, etc., it is desirable. If this is not possible, and preventive maintenance work causes otherwise productive machines to shut down temporarily, the scheduling department is usually responsible for scheduling times for preventive maintenance.

The dovetailing of schedules is usually done by setting up the maintenance schedule *before* any productive work is scheduled. Usually the productive work can then be loaded into the machines without conflict. If a conflict does arise, preventive maintenance is normally moved up or back in the schedule to resolve the problem. Scheduled maintenance can also be used to give the system a little more flexibility. For example, if an operation becomes delayed, the postponing of a maintenance period may enable that order to get back on schedule. Therefore, in such cases, the scheduler must be aware of all planned commitments of the maintenance department and the men available to perform them. Also, he must bear in mind that by deferring maintenance he increases the chance that the machine will break down, thus causing more delay than would have occurred otherwise.

Summary

The actual process of scheduling follows these basic steps:

1. Develop the master schedule based on the overall plant or department capacities, and existing orders or sales forecasts.
2. From the master schedule, develop a more detailed schedule based upon department or individual machine capacities.
3. Issue the necessary instructions to put this schedule into effect.
4. Obtain feedback as to actual compared to planned performance in the shop.
5. Readjust the schedule periodically.

3

Alternative Scheduling Methods

The previous chapter described the scheduling problem in a typical "job shop" type of manufacturing situation. Such applications comprise a large part of scheduling applications. There are some unusual cases, however, which occur frequently enough in practice to have special systems developed for them.

Load Control

Normally, individual machines are not scheduled in detail on a job-by-job, hour-by-hour basis. It is usually sufficient to schedule by class of machine and/or job, and then to release jobs in order of priority. An exception is sometimes made in the case of large and expensive machines, or machines that form a critical bottleneck in a department. Such machines may be scheduled in detail, using some form of Gantt Chart (described in Chapter 4) or similar scheduling device, with the starting and finishing times of each job, as well as setup times, operator breaks, etc., planned ahead. This is usually referred to as "load control."

Block Control

The normal production control system can be considerably simplified if the following conditions exist:

1. All products take roughly the same time to make.

2. All products go through the same series of steps during manufacture.
3. The departments performing each step are in capacity balance—i.e., each can produce the same number of products (or sets of parts) in the same length of time.

Under these conditions, orders can be accumulated in batches of similar products until the batch is large enough to fully occupy each department for a given time period, often one day. This batch of orders is then released to production as a "block," hence the name "block control." Control in this case consists of checking that the complete batch is finished within the allotted time period. If it is not finished, either the next batch is made slightly smaller, or those products that were not completed in the first batch are included in it. Individual orders need not be scheduled separately, and complicated juggling of routings and finish dates is not necessary.

The required conditions apply in a surprising number of industries, from the manufacture of men's clothing to the writing of insurance policies.

Short-Interval Scheduling

Short-interval scheduling has much in common with block control, though it can be used in a wider variety of circumstances. In principle, it consists of releasing work to operators in batches covering a given time period (usually an hour to half a day), just as in block control. At the end of that period, the operator reports whether the batch is complete, and if so, receives another batch. However, unlike block control, batches are given out to individuals (or small groups), not to the complete plant, so the necessity for capacity balance does not apply.

Short-interval scheduling is usually aimed more at increased efficiency than at improved scheduling per se. It provides the operator with a "quota," and the incentive to complete it on time, and it draws attention to schedule slippage within an hour or two, so that problems causing it can be quickly corrected. Where these elements are critical, it can be of tremendous value.

As short-interval scheduling is relatively expensive to install and maintain, care should be taken in applying this technique. Generally, it should be utilized only if substantial benefits can be obtained through establishment of quotas and through rapid detection of problems and schedule slippage.

Process Control

Process control is applied to situations in which the plant is basically a single facility performing a series of operations on similar parts or ingredients. It is not usable with a collection of different and partly interchangeable machines making different products. Two good examples of facilities in which process control would apply are a chemical plant and an automobile production line. In a chemical plant the "routing" (flow of chemicals through the plant) and capacities have already been largely determined by its design. In fact, if consistency of raw materials and reliability of the equipment can be guaranteed (and this is sometimes the case), the need for production scheduling is eliminated.

However, most raw materials, whether metal ore, wood pulp, crude oil, or whatever, vary somewhat in their physical makeup and characteristics. Therefore, the time required to put them through various processes also varies. Also, catalysts may slowly lose their power, pipes can become partially clogged between overhauls, and these effects can change production rates in parts of the plant. The job of production scheduling then becomes one of balancing the various rates of flow and chemical change.

In the case of an automobile plant, the production rate has been largely set by the speed at which the line has been designed to run. Moreover, the plant produces basically one product, automobiles, even though the variations in that product in terms of color, model, engine size, additional equipment, etc., run into many thousands. In this variety lies the scheduler's problem. Mr. Smith has ordered a blue, six-cylinder car with red upholstery, air-conditioning, and a tachometer. At some point in the assembly line, therefore, a blue body shell must match up with a six-cylinder engine. At another point, it must match up with blue doors, and so on.

The problem lies in coordinating all the many subsidiary lines which bring various parts to the main assembly lines. This very complex task is performed by a computer system which has the parameters of the assembly line programmed into its memory and, therefore, knows that when Mr. Smith's blue car reaches position 14 on the main line a set of blue doors must be placed on the door line at position 31, and that a set of red upholstered door panels must enter a subdivision of the door line at position 341 exactly 3½ minutes later. What the computer actually does is work back from the "delivery date" (in this case, the time the completed car will leave the line) through all the parts and sub-assembly stages to a "starting date" for each part in just the same way as is done in a machine shop, except that the job must be done with far greater accuracy.

The other critical aspect of this kind of scheduling is the maintenance of a small, but sufficient quantity of the correct parts in inventory. Because of the bulk of some of these parts, and the huge amounts of money tied up in their storage, automobile manufacturers maintain less than a day's stock of some components. A careful watch must be kept on the kind and quality of parts in stock, since the shortage of one key part could stop the whole production line.

Maintenance and Repair Shops

A maintenance and repair shop generally operates a scheduling system that is similar in principle to the system described in Chapter II. However, the special difficulties of this type of work present special problems.

The first problem is that most of the work arrives with no advance notice, and is urgent because it is composed of machines (whether automobiles, earth-moving equipment, or heating systems) that have broken down, and must be put back into service as fast as possible.

The second problem is in establishing in advance the work content of a job and the length of time it will take. Often a mechanic cannot tell whether a simple adjustment or a major overhaul will be needed until he starts to disassemble the machine.

Both of these difficulties simply mean that the schedule must be far more flexible for a repair shop than for a manufacturing plant. The schedule must be simpler and must be capable of faster and more frequent adjustment. Fortunately, regular "preventive" maintenance work and rebuilding of components not urgently needed can be used as "fillers" between the urgent breakdown jobs. Also, more "slack" is usually allowed in the schedule than a manufacturing company could tolerate. However, the key to success remains the ability to change the schedule easily and often.

4

Technical Aids To Scheduling

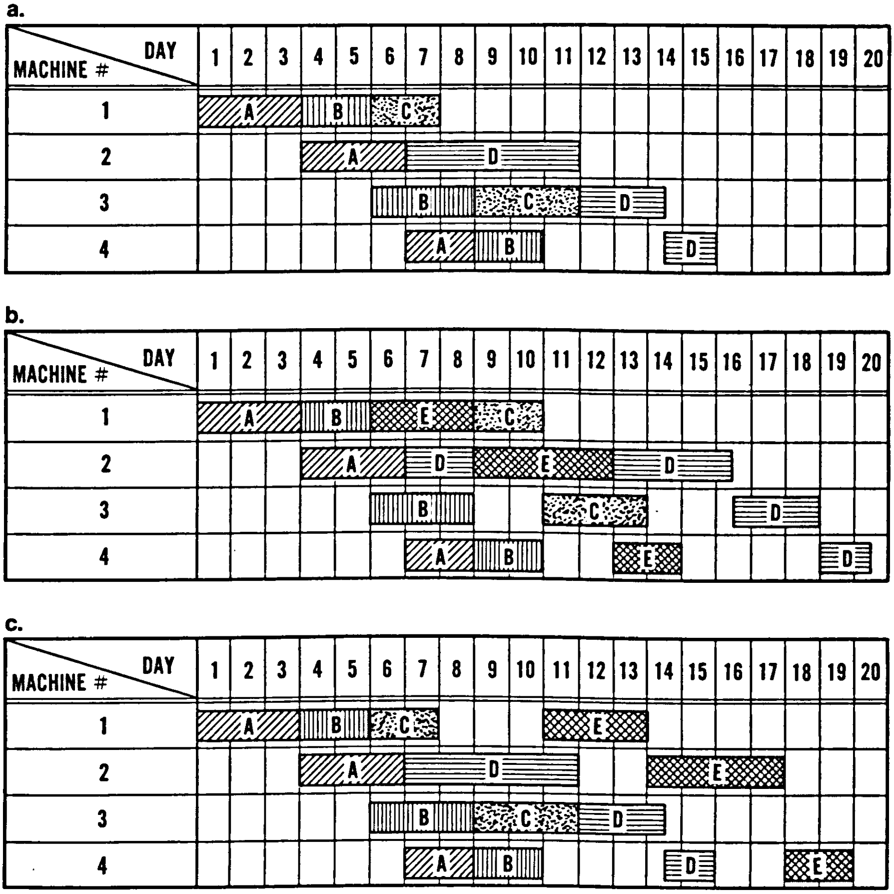
The previous chapter indicated that, while production scheduling is simple in principle, it can become very complex in practice. In complex situations it requires a large number of interrelated decisions at the same time or at frequent intervals. Except for the simplest systems, the human brain cannot remember and juggle all the relevant factors at once. For this reason, a number of aids and techniques have been developed to help the scheduler keep track of all the various factors that he must coordinate. Some of these techniques help him visualize these factors more easily; others can even make some of his decisions for him. The simplest and oldest of these aids is probably the Gantt Chart.

Gantt Charts

A Gantt Chart simply helps the scheduler to visualize the current load in the plant, and to see the effects of altering it. It consists of a chart or board, with a time scale along the top and the machines or work centers listed down the side. Lines (or cards) are placed opposite each machine to represent each job the machine will perform. The length of each line is proportional to the time the job will take. The top chart in Figure 8 on page 32 is a simple example of a Gantt Chart.

Suppose that a new product, Product *E*, is introduced into the schedule and that it will require three days on machine 1, four days on machine 2, and two days on machine 4. Suppose it must also be finished by the end of day 15. The new chart might look something like the middle chart in Figure 8.

FIGURE 8 Example of a Gantt Chart



The insertion of this extra job has had several unfortunate effects. In order to meet the deadline for *E*, the completion dates for *C* and *D* have had to be postponed. Moreover to avoid delaying *D* too much, the plant will have to start working with *D* on machine 2, then change to *E* as soon as it is available off machine 1, then change back to *D* when *E* has been completed on machine 2. This will waste an additional half day on machine 2, because of the extra setup time required. *E* will actually be completed by the end of day 14; there is no advantage in delaying it until day 15.

If the completion date could be deferred until day 19, the picture could change, as illustrated by the bottom chart in Figure 8. Under this circumstance, other jobs are not delayed—in fact, all machines have spare time in which more urgent jobs could be inserted before *E*. It is also easy to see that the earliest time *E* could be finished without delaying other jobs is day 17. This is an excellent example of the value of a realistic promise date and the problems that "reshuffling" rush orders can cause.

Various commercial companies sell a variety of metal, plastic, magnetic, and other types of scheduling boards to facilitate the scheduling practice. Most production scheduling and inventory control trade magazines have a number of advertisements in each issue for a wide range of different types of boards. With these boards, schedule adjustments can be made easily and various order sequences can be tried. On the boards, a job is usually represented by a card cut to length to represent the duration of the job. The cards are placed in slots marked with the time scale and machine numbers, or they are affixed to the board in some other, similar arrangement. The board doesn't make decisions, but it does help to visualize current machine loadings and the effect of inserting new orders. Yet, even with such boards to help the scheduler, complex situations can get out of hand. There are often so many possible ways of arranging jobs that it becomes very time-consuming to try enough different arrangements to arrive at the most suitable one.

Critical Path Planning

An aid of the same type, but much more powerful, is called "Critical Path Planning" (also called "Network Analysis," "Arrow Diagrams," "Critical Path Method" or CPM). In this technique, the various jobs are represented in a network and are connected in logical sequence. A simple example will illustrate the method. Figure 9a, page 34, shows the steps involved in making a lampshade, and the length of time each step takes for a batch of 100 lampshades.

The first task in critical path planning is to establish the logical sequence of steps. This is done by listing the "predecessors" of each job, as shown in the last column of Figure 9a. From this chart it can be seen that the following tasks must be done first: cutting the wire to length, stamping out the shade brackets, and cutting out the cover material. The wire cannot be bent into the shape of the frame until it has been cut, nor can the bracket be welded to the frame until the frame has been welded and the bracket has been stamped out.[1] This is the first advantage of Network Analysis—it forces the planner to think of the logical relationship between the steps, which is often far from obvious from a mere list.

FIGURE 9a Critical Path Planning

Lampshade Manufacture—Operation Sheet

	Operation	Time Per 100 (Minutes)	Predecessors
A	Cut wire to length	3.00	—
B	Bend wire to form frame	9.00	A
C	Weld wire	7.50	B
D	Stamp out shade bracket	4.00	—
E	Weld bracket to frame	7.00	C, D
F	Spray-paint frame	14.00	E
G	Cut out cover material	5.00	—
H	Edge cover material	12.00	G
I	Fix cover to frame	11.50	F, H
J	Inspect	6.00	I
K	Pack for shipping	6.50	J

Having established the necessary sequence of jobs, a diagram, representing each job by an arrow can be drawn, as in Figure 9b, page 35. Steps A, D and G can start at once, since they have no predecessors. Step H can follow step G, step B can follow step A, step C can follow step B, and step E can follow step C. But step E can *only* follow step C if step D has also been done. To indicate this on the diagram, the end of D is joined to the beginning of E with a dotted arrow, called a "dummy." The construction of the diagram continues in the same way until step K has been completed.

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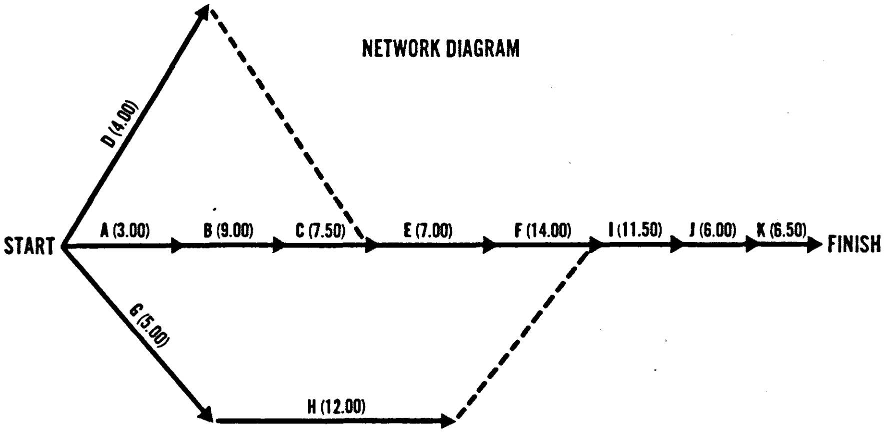
[1] Of course, by beginning to weld the first frame while the last frame wires are still being cut, the steps could be overlapped to some extent. For the sake of simplicity, however, it will be assumed that successive steps are performed at different locations, making this impractical in this case.

What can this diagram tell us? First of all, some jobs have "slack" time, and others do not. Step D, for example, takes four minutes, but if for some reason it happened to take eight minutes instead, the whole job would not be delayed because the bracket would still be ready for welding to the frame by the time the frame was ready. Any delay in step A, however, would delay all subsequent steps, and therefore the whole job. There is, in fact, a series of steps which have no "slack" time. These are indicated by heavy arrows in Figure 9b. This series of steps is called the "critical path," from which the technique gets its name.

Thus the network tells us that some steps can be delayed without delaying the job. If the stamping machine is busy on another job when the 100 lampshades are started into production, it can be left working on that other job for another 15½ minutes before it is changed over to lampshade brackets, and still the 100 lampshades will be finished on time. But the cutting of wires must start immediately, and the bending machine must be ready three minutes later. Similarly, if the planner wishes to finish the lampshades earlier than originally planned, there is no point in speeding up step D. One or more of the jobs on the critical path must be speeded up in order to do this. If two spray

FIGURE 9b **Critical Path Planning**



Note: Letters indicate various operations. Numbers in parentheses indicate minutes per 100 pieces for each operation.

booths were available, for example, they might both be used on step F, and the lampshades would be ready seven minutes earlier. This introduces another value of network analysis: resource allocation. Two spray booths can be allocated to step F to speed the job up, but a second stamping machine is unnecessary. Consider another example. If one man performed all the steps, how long would it take him? Obviously, the sum of the times for all steps, or 85.50 minutes. If a second man is allocated to the job, how long will it take? Well, one man can perform all the tasks on the initial path, taking 64.50 minutes, while the other performs steps D, G, and H. What if a third man is assigned? It won't help a bit. Even if both spray booths are used, the second man can perform steps D, G, and H and operate the second spray booth, and still have everything ready for the first man before he needs it. The third man would have nothing to do.

This example is a very simple one. A normal critical path diagram used in practice will probably have several thousand arrows, instead of 11. It is virtually impossible to draw such a diagram, and so computers are used to store all the relevant information and perform calculations in a way similar to, but much more complex than, the example given. Standard computer programs are available that will perform these analyses and determine the costs of various alternatives.

Thus, Critical Path Planning helps to examine a sequence of jobs in a logical manner, to determine which jobs are critical and which are not, to determine resources required and to show the results of allocating those resources in various ways.

PERT

The Critical Path Method, as just described, is useful when operation times can be predicted with reasonable accuracy. This is true in most normal manufacturing situations, especially when standard times have been documented. It may not be true for projects that are done infrequently or that are to be done for the first time. Thus, in the major overhaul of a chemical plant, the scheduler will not know how long each operation may take until the plant is already shut down. In building an oil tanker or new design, some tasks may be performed for the first time, and their duration can only be guessed.

In cases like these, a development of critical path planning, called PERT ("Program Evaluation and Review Technique") is useful. It is basically the same as Critical Path Method but for one thing—the time estimates of the duration of each task are arrived at differently.

The method is to get (from people intimately involved with each state of the project, or from acknowledged experts in the particular field involved) three time estimates for each job, rather than one. These are an "optimistic" estimate, a "pessimistic" estimate, and a "most likely" estimate.

These estimates are combined to give the "expected" duration of the task, which is the one actually used for drawing the network and calculating overall project times. This "expected" time is calculated as follows:

$$\frac{\text{pessimistic time} + 4\,(\text{most likely time}) + \text{optimistic time}}{6}$$

Thus if the project engineer responsible for overhauling a chemical plant felt that a certain reactor could not be cleaned in less than ten hours, could take as long as forty hours, but would most likely take fifteen, the "expected" time used for planning would be

$$\frac{10 + 4(15) + 40 \text{ hours}}{6} = 18.3 \text{ hours}$$

By calculating job times in this way for each step of the project, the network can be drawn and used in the same manner as under the Critical Path Method.

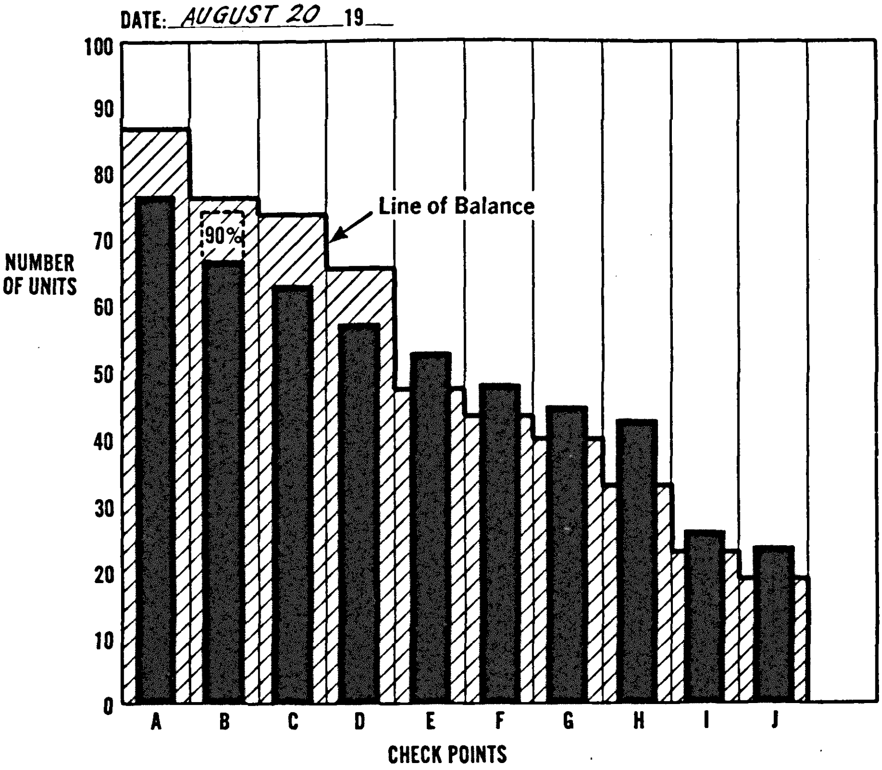
Line of Balance (LOB)

When Critical Path Method and PERT are used for complicated projects, it becomes a time-consuming task to check on whether progress is according to plan or not. Therefore a technique has been developed to help. It is called LOB, which is short for "Line of Balance."

Briefly, it works like this. Suppose the first batch of 100 primary control systems for a new aircraft are to be made. The network diagram, PERT diagram, or for that matter, a normal production schedule, will indicate how many of the 100 units should have passed each stage in the manufacturing process by a certain date. This information can be shown on a bar chart, as in Figure 10, page 38. Here, 88 units should have completed stage A, 77 should have completed stage B, and so on, down to the 19 units which should be through stage J. These various quantities can then be connected by a stepped line, which is called the "Line of Balance." Bars representing actual progress on a given date can be added to the chart. In Figure 10, 78 units have actually completed stage A, while 25 have completed stage J. The "ghost" bar above stage B means that, while only 67 units have completed stage B, a further 8 units are within 90 percent of completing it.

The chart shows at a glance that, while later stages of the project are ahead of schedule, earlier stages are falling behind. It directs the scheduler's attention particularly to stages A, C, and D, which seem to be the main problem areas.

FIGURE 10 **Line of Balance Chart**



Linear Programming

A technique which can, under certain circumstances, make decisions *for* the scheduler, is called Linear Programming. The "certain circumstances" will be considered later; meanwhile, the technique can best be illustrated by an example.

Consider a plant making two kinds of domestic freezers—small and large. The department that produces the freezer cabinet can make 10,000 large freezers or 12,000 small ones in an eight-hour day. The motor department can make 16,000 motors for the smaller freezers, or 8,000 for the larger ones. The freezers are assembled on two separate lines. The line for the smaller units can make 8,000 freezers, and at the same time the other line can assemble 6,000 large freezers. Given that the smaller freezer makes a profit of $9 and the large one a profit of $12 (and assuming happily that the maximum production of either kind of freezer can always be sold), how many of each kind should be scheduled into production in order to maximize profits?

It might appear that as many large freezers as possible should be made since they produce more profit per freezer. The most that can be made is 6,000 since this is the capacity of the assembly line. Only 4,000 small freezers can now be made, since this is the maximum number of motors the motor department can produce after making 6,000 large motors.[2] Hence our profit would be 6,000 large freezers × $12 plus 4,000 small freezers × $9, or $108,000.

But suppose as many small freezers as possible were made? Production is limited to 8,000 by the small freezer line. This in turn, by a calculation similar to the previous one, limits the plant to 3,333 large freezers, because this is the maximum amount of cabinets that can be made for large freezers, after making 8,000 for small freezers. The profit is now 8,000 small freezers × $9, plus 3,333 large freezers × $12,

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[2] The motor department makes large motors at $\frac{8{,}000}{8}$ per hour, or 1,000 per hour. 6,000 large motors therefore take six hours to make. Small motors are made at $\frac{16{,}000}{8}$ or 2,000 per hour — therefore only 4,000 small motors can be made in the remaining two hours. A similar calculation shows that 4,800 small cases could be made, although this would obviously not be sensible, since there are not enough motors to put in them.

or $111,996—almost $4,000 more than the previous strategy. A lower profit per freezer is more than compensated for by being able to sell more freezers.

But perhaps the plant can make even more profit by making some other combination of large and small freezers? This is where Linear Programming can help.

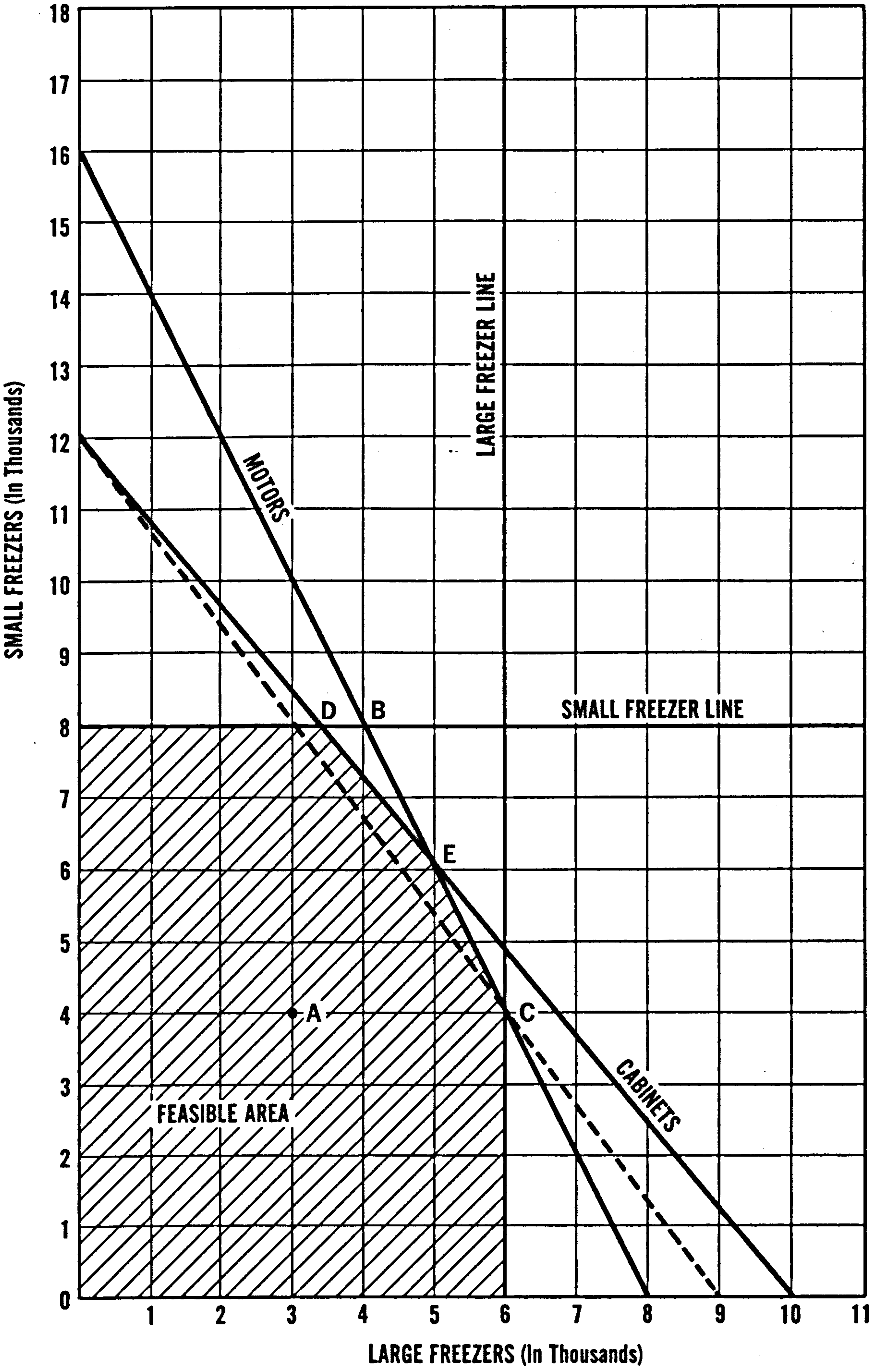
Linear Programming provides a method of finding the best solution to a problem where there is a definite *criterion* to be met (in this case, to obtain maximum profit), and where the situation is limited by a set of *constraints* (in this case, the production limitations of the motor department, the cabinet department, and two production lines). Such situations are frequently encountered in production scheduling.

The above example can be solved with the help of a graph. In Figure 11, page 41, the axes of the graph have been established with the number of large freezers (in thousands) along the horizontal axis, and the number of small ones on the vertical axis. Next, the constraints are drawn in. The limitations of the two production lines are horizontal and vertical, since the small freezer line can make 8,000 small freezers irrespective of the number of freezers made on the other line. However, the motor department can make 16,000 small motors or 8,000 large ones. Therefore, if these two points are joined on the axes of the graph with a straight line, this line will represent all possible combinations of large and small motors. The same is done with the limitations of the cabinet department.

The graph now shows what is called the "feasible area," indicated by shading. Within this area, any combination of freezers can be made. Outside this area, one or more constraints prevent the plant from making the number of large and small freezers indicated. For example, point A represents 3,000 large freezers and 4,000 small. This is within the capacity of both lines, the motor department and the cabinet departments, and so is feasible. Point B, representing 4,000 large and 8,000 small freezers is not feasible. It is within the capacity of both lines and the motor department, but the cabinet department cannot make that number and combination of cabinets in the day.

If the plant can sell all it makes, management will want to use as much of the capacity of the plant as possible, so our best (i.e., highest profit) solution will probably be point C, D or E. A brief inspection will show that points C and D are the two situations worked out earlier. It was found that D was more profitable than C, but perhaps E would be more profitable still?

FIGURE 11 Linear Programming—Graphical Method



It would be possible to work out a further calculation for 5,000 large and 6,000 small freezers, but there is an easier way to judge if E is the best solution. Since small freezers make a profit of $9 and large ones $12, a dotted line is drawn between the figure 9 (or any multiple or fraction of it) on the *large* freezer axis, and the figure 12 (or the same multiple or fraction) on the *small* freezer axis. Now the point furthest to the right of that line (or closest to it, if it should lie outside the feasible area) is the best solution. Point B is further to its right than C, which confirms the earlier conclusion, but E lies further to the right still. A calculation confirms this: at point E the plant makes 5,000 large freezers × $12 plus 6,000 small freezers × $9, or $114,000.

Let us now assume that the plant makes five different sizes of freezers. In such circumstances it is impossible to solve the problem graphically, since no one has yet invented a five-dimensional graph. However, other methods are available, chief of which is a tabular solution called the "simplex method." The interested reader should consult AICPA Management Services Technical Study No. 8, "Management Information Systems for the Smaller Business," since a full treatment of this technique is beyond the scope of this study. However, any manual method becomes awkward if there are very many variables. In such cases, standard computer programs are available for performing the calculations. The principle and the result, however, are the same as those illustrated in the graphic example.

Queueing Theory

"Queueing Theory," or "waiting-line theory" is frequently thought of as applying to problems of staffing gas stations, bank teller or supermarket checkout lines, etc. In fact, however, it is applicable to any production scheduling situation where work is done, and the facilities available for doing it (people, machines, or whatever) behave as follows:

1. Work to be done arrives at random intervals, although over a long period of time the average number of arrivals is roughly constant.[3]

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[3] The theory actually assumes that arrival times follow a Poisson distribution.

2. The time to perform each item of work varies randomly, but again conforms to a long-term average.[4]
3. The number of men (or machines) performing the work is constant.

This kind of situation occurs frequently in scheduling. The problem is usually to determine the ideal number of men or machines in any given situation. In Queueing Theory, the number of jobs arriving in any given time interval is called the "arrival rate" and the number of jobs that can be done in the same time interval is the "service rate."

Suppose a company is in the business of overhauling electric motors, and it has one man and one machine available for renovating commutators. The time taken to do this varies, but is on average 15 minutes. Thus the "service rate," which is represented by the Greek letter γ, is four jobs per hour. Suppose that on the average the machine receives 7 commutators for overhaul every two hours, so that the arrival rate, represented by the Greek letter λ, is 3½ commutators per hour.

If commutators arrived regularly at a constant rate of 3½ per hour, and our worker *always* took 15 minutes to renovate them, there would be no problem. But this is not the case. Sometimes commutators will arrive much more rapidly, and the operator will take more than 15 minutes to repair them, so that a line of commutators awaiting repair will start to back up. At other times, commutators will arrive less frequently and will take less time to fix, so the operator will have periods of idleness. The scheduler will therefore be interested in the average time each commutator will spend waiting to be fixed, and being fixed, and in the average amount of time the operator will have nothing to do.

According to the theory (which is not proved here, since the interested reader will find a full discussion on it in any operations research text), the average number of commutators waiting for overhaul will be

$$\frac{\lambda^2}{\gamma(\gamma-\lambda)}$$

Which in our example is

$$\frac{3.5^2}{4(4-3.5)} = \frac{12.25}{2} = 6.125$$

---

[4] The theory actually assumes a negative exponential distribution for time to complete each task.

The average number of commutators being overhauled and waiting for service will be

$$\frac{\lambda}{\gamma-\lambda}, \text{ or } \frac{3.5}{4-3.5} = \frac{3.5}{.5} = 7$$

Note that this second answer is *not* the same as the number waiting for service, plus the one being serviced. A moment's reflection will show that this is because there will sometimes be no commutator being overhauled (as when the man is idle). In this case, the average number of commutators actually being serviced is less than one.

Average time required for a commutator to be serviced, including its waiting time, is

$$\frac{1}{\gamma-\lambda} = \frac{1}{4-3.5} = 2 \text{ hours}$$

Average time waiting for service (not including service time) is

$$\frac{\lambda}{\gamma(\gamma-\lambda)} = \frac{3.5}{4(4-3.5)} = \frac{3.5}{2} = 1.75 \text{ hours}$$

In this case, total time for waiting and overhaul *is* equal to the average waiting time plus the average overhaul time.

The average idle time of the man is the difference between the arrival rate and the service time, or

$$\frac{\gamma-\lambda}{\gamma} = \frac{.5}{4} = 12.5\%$$

The above problem represents a "single-channel" problem: only one man is available through whom all commutators must pass. More common is the multi-channel problem. In multi-channel problems, the mathematics gets much more complex. However, the solutions follow the same basic logic pattern. With the availability of computers these solutions can be readily developed.

Queueing Theory can help in scheduling jobs whose time varies, and which tend to arrive at varying intervals, by giving the scheduler some idea of the average backlog he can expect, and by giving him a means of deciding whether he should increase capacity or not. It is particularly applicable to maintenance work, and to the issuance of materials and tooling from stores. However, as indicated, the mathematics involved is complex and can become virtually unmanageable in some situations.

Simulation

Monte Carlo Method

In simulation, a "model" of the scheduling situation is established, then operated multiple times under a variety of circumstances to determine what is likely to happen. Consider the problem of painting a large, exposed bridge-crane. Three basic operations are involved—stripping the old paint, applying the primer, and putting on the new paint. The time each job will take will depend on the condition of the present paint, weather conditions, whether the estimator correctly estimated the total area to be painted, and so on. Moreover, if the stripping job turns out to be quick and easy, the priming job probably will be too. Suppose a diagram is drawn covering a variety of possibilities, as in Figure 12, page 46. Each branch in this diagram represents a possible time for the job. Suppose, on the basis of past experience, the planner can add probabilities to these times. He knows, for example, that there is a probability of 0.3 (i.e., a 30 percent chance) of stripping the old paint in three days. The symbol "P = .3" is put on the "3-day" branch to indicate this.

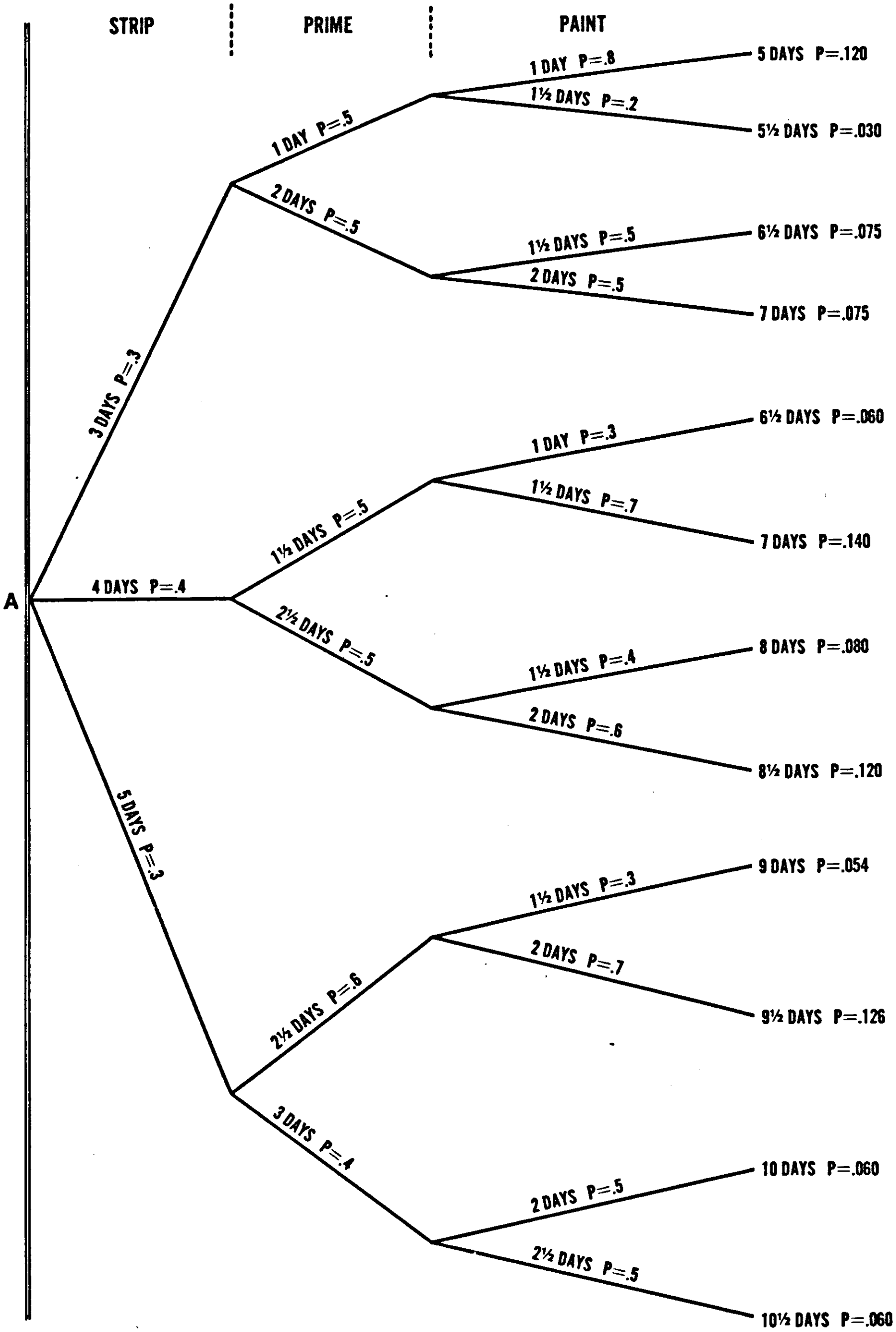
The total time for each possible branch can be totaled and put in the last column. The probability of reaching the end of each branch can also be calculated by multiplying the several probabilities along the way. For example, the probability of finishing the job in five days (the topmost branch) is .12, or .3 × .5 × .8.

The planner now knows a great deal about this job, even though he cannot forecast its duration with certainty. For example, he will be relatively sure that it will not be done in less than 5 days or more than 10½ days. He knows he has a 50 percent chance of finishing the job in 7 days or less (this can be shown by *adding* the final probabilities of all the branches resulting in 7 days or less). Depending on the circumstances, he might decide to plan on 9½ days for the job, and he could then work out the probability of missing the deadline (.12, or 12 percent), or beating the deadline by any given number of days.

This information is particularly useful if a series of major equipment items must be painted. However, a diagram covering, say, twelve pieces of equipment would have so many branches that it would be unmanageable.

Therefore, another technique is used. It is called the "Monte Carlo" method of simulation, because it depends on chance. Instead of trying to draw all the branches on paper and calculate the values for thousands of end-points, all the information needed to draw such a diagram

FIGURE 12 **Industrial Crane Painting**



is programmed into the memory of a computer. It is programmed so that the computer simulates actual practice by means of a "random number generator" within it. The planner can simulate actual conditions at point A (see Figure 12, page 46) for example, by telling the computer to choose three days for stripping if the random number generator throws up a number between 0 and 29 (corresponding to the .3 probability for this time), four days between 30 and 69, and five days between 70 and 99. The computer does this at every branching point, and finally arrives at a total time for the job—say, seven days.

In itself, this single solution is not very helpful. It is already evident that the job *could* take seven days. To arrive at a more meaningful solution, the computer repeats this process many times using different random numbers. It might repeat it a hundred or more, or even several thousand times. The result is a probability distribution of total times for the job, which provides the same sort of valuable information that Figure 12 does for a simpler case.

Systems Simulation

In the most complex situations, even the Monte Carlo method of simulation becomes unwieldy. Even though the computer can handle many more variables than a man, the number of branches and possible outcomes can become unmanageable. In such cases the actual production schedule itself can be used for simulation experiments.

The production schedule, when computerized, becomes a "model" of what happens, or what is intended will happen, on the shop floor. Such a model incorporates factual and estimated data, such as specifications, routings, capacities, and deadline dates provided by the production scheduling department. It also incorporates "decision rules" which order the computer to make certain predetermined choices under certain well-defined circumstances. When these facts and estimates, representing the best knowledge that the scheduling department has, are fed into it, the computer can produce a production schedule.

Suppose, instead of giving the computer actual facts and realistic estimates, it is given information *as the scheduler would like things to be?* For example, suppose the scheduler feels that the purchase of an additional machine for a bottleneck operation might be advantageous. He could enter information into the computer indicating that the plant has the machine, let it develop a new "hypothetical" schedule, and compare it with the actual schedule. If it shows marked benefits, it would indicate that the purchase of an additional machine may be worthwhile. In this way, the results of a variety of "hypothetical" changes can be evaluated, such as a reduction of inventories, a reduction in transit time between work stations, and so on. The computer will show the effect of each change without the need to try it in practice and without the risk of encountering unknown results.

This kind of system simulation is a powerful tool, but it lacks one element that is present in the real situation—feedback. The simulation can produce a schedule, but it cannot predict how well the schedule will work in practice.

It is possible, however, to program the computer to provide its own simulated feedback. Suppose, for example, that past records show a certain machine breaks down with a certain frequency. The computer can be given this information, and all other like information, and programmed to simulate the results of a "hypothetical" schedule with all the attendant schedule slippages, machine breakdowns, and so on. Such procedures involve a sophisticated and expensive system that can only be justified for large plants involved in numerous major decisions requiring the evaluation of alternative actions or schedules.

5

Trends in Production Scheduling

The role of production scheduling in the overall production operation has been gaining increasing importance in recent years and will doubtless continue to do so. There are many reasons for this. Manufacturing has tended over the years to become a more and more technical undertaking and is being done in plants that make a wider and wider variety of products and require a more and more systematic approach to production. More powerful tools, both physical (computers) and intellectual (operations research techniques), have increased its scope.

Computers

The event that has made the biggest single impact on production scheduling in the last decade has been the development of the computer.

The computer was first used in business to automate routine clerical work, and this is still its main application. Thus, many large- and medium-sized plants set up a production control system in the same way they would if it were to be administered by a clerical staff and then program it and run it on the computer. The computer does not make any decisions (except those that have been programmed, and therefore, made in advance); it simply absorbs the data, does the necessary calculations, and prints out the results faster and, if necessary, more often than a manual system.

Integrated Computer Systems

Companies that have several of their information subsystems (such as payroll, accounts receivable, accounts payable, production scheduling, and inventory control) programmed on the computer benefit from designing these systems to be compatible with one another. This means that the output from one subsystem (e.g., material scheduled into production by the production system) can be used as input to another subsystem (e.g., the inventory control subsystem) in order to update inventory records and generate reorder instructions without the need to "translate" it into another form. Human intervention is frequently required to accept the output of the first subsystem and offer it to the second subsystem, and perhaps to make some checks or even some decisions before doing so. One such check, for example, might be altering the reorder point on a particular stock item in response to a changing rate of demand.

Some companies are taking this idea one step further, and allowing one subsystem to automatically feed the next without any human intervention. For example, instead of just printing out requirements lists for the stockroom, the computer may feed this information into the inventory control system, check the stock records, and issue stock releases for material that it finds in stock and purchase orders for material it finds out of stock or running low. This saves time and, if the systems are properly set up, reduces the possibility of error.

It would be theoretically possible (though presently rather impractical) to set up computer systems to integrate all the different operations of a business, right from personnel records through to printing financial reports. Some company may some day do this type of thing. So far no company has attempted it, however, because of the mammoth task of systems design involved, the difficulty of preprogramming all the decisions in advance, and the difficulty of tracing errors in such a complex system. But some companies are deriving significant benefits from computerized scheduling systems that are integrated with other closely related functions, and in time, more and more integration will probably be attempted.

Simulation

The most recent, and perhaps the most far-reaching, development the computer has made possible in the scheduling field is large-scale systems simulation, as described in the previous chapter. At present its use is limited to applications in which the benefits can offset the extremely high cost of developmental manpower as well as hardware. Current trends toward cheaper, yet more sophisticated, computers and flexible packaged programs may eventually make these techniques practicable in a much wider variety of production and business applications. In particular, the combination of integrated systems and systems simulation, though still years away from general availability, may eventually revolutionize the manufacturing function.

Organizational Trends

Traditionally, the function of the production scheduling department has been limited to routing and scheduling parts, subassemblies, and products from the raw material stage to finished product awaiting shipment in the warehouse. Many other departments, such as traffic (both external and intracompany), inventory control, purchasing, and shipping coordinated their activities with the scheduling department but were not directly under its control. This is still the case today in a large number of companies.

However, an increasing number of firms are now using the concept of a single "materials management" function, whether or not they call it by that name. Under this concept, the materials management department is responsible not only for scheduling and planning the movement of material through the plant, but also for providing the material in the first place, planning its transportation into, out of, and within the plant, and its shipment on completion. Therefore, in these cases, departments such as purchasing, inventory control (for raw materials and finished goods, as well as work in process), traffic (both incoming and intraplant), and shipping are combined with scheduling and are subsections of the materials management department.

In some companies, the "materials management" trend has been taken even further to the point where an "operations management" department is given virtually the full responsibility for production, including responsibility for all "staff" manufacturing activities. Factory "line" supervision retains responsibility for little more than the provision of men and machines.

This trend is taking place because in many industries the growing size and complexity of manufacturing plants make the coordination between a variety of separate departments extremely difficult. In addition, the computer has provided closer coordination of systems. For example, it was pointed out in Chapter 3 that in the automobile industry the close control of raw material inventories is vitally important to effective scheduling. If the scheduling system and the inventory control system are integrated on the computer, it makes little sense to have two different departments responsible for them. The trend will undoubtedly extend to more and more companies as industrial operations become increasingly complex.

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The Corcoran Pipe Company

The following case study is presented as an example of how an alert CPA can assist a client by identifying a problem area, alerting the client, and taking the initiative in assisting his client to solve the problem.

The Problem

Arthur Ellis, a partner in a well-established CPA firm in the city of Woodnesborough, Pennsylvania, had just finished an audit for one of his clients, the Corcoran Pipe Company. He called at the office of the company president, Mr. John Corcoran, to report that the task was completed. Several matters that seemed to require management's attention had suggested themselves to Ellis during the audit, and he proceeded to outline these to the president. After some discussion, Mr. Corcoran said:

"Arthur, you've mentioned several areas where you feel our costs could be reduced, and I will certainly study your recommendations in detail. However, there's one area I'm really concerned about because it's hurting our costs more than anything else, and that's the workflow in the plant. When I built this plant over ten years ago, things ran pretty smoothly, but now we have a rash of bottlenecks and late deliveries, and our production time has increased from an average of eight weeks to well over fourteen. I know the reason—our volume is up nearly 40 percent, and the mix of products has changed quite a bit. But, short of rebuilding the whole plant, I'm not sure where to look for the solution."

The Company

The Corcoran Pipe Company was formed in 1928 by the late William T. Corcoran, father of the present president. For many years it manufactured small- and medium-diameter steel pipe by the continuous weld or "CW" method. This method employed a flat strip of steel, which was heated by passing it through a furnace, then formed into a tube by a series of rollers. The edges of the strip were brought together under pressure, and welded together automatically because of the high temperature of the strip. The pipes were sold to a variety of customers, chiefly in the construction industry.

When John Corcoran succeeded his father to the presidency in 1950, he immediately introduced a more modern process, whereby the steel strip was bent into a tube in the cold state, then welded by passing a powerful electric current across the joined edges of the strip. This process (called "ERW," which stands for electric resistance welding), while somewhat more expensive than the hot-forming method, produces a much higher quality pipe. The new venture was increasingly successful, and in early 1958, John Corcoran built a new plant incorporating high-volume electric weld machinery. He included one of the old hot-forming machines, however, since the low-cost pipes it produced still found a ready market in many industries.

The Pipe Making Process

The process of actually making the pipes was relatively simple. Different sizes of pipe would be made by using strips of different widths, and fitting rollers of the appropriate size to the forming machine, or "mill." The pipe mills had been designed so that changes of size could be made relatively quickly. However, the mills were limited in the range of sizes they could make, as follows:

Mill #1 (ERW) ½" to 2½" O.D. (outside diameter)
Mill #2 (ERW) 1½" to 4" O.D.
Mill #3 (ERW) 3" to 6½" O.D.
Mill #4 (CW) 1½" to 6" O.D.

Pipes were normally cut into 30-foot lengths (the usual length ordered) as the machines produced them. All pipes then passed through a straightener and a surface inspection. They might go through a variety of additional processes, depending on the customer's needs. Some pipes were threaded or "screwed" at the ends and were then fitted with connectors or with plastic endcaps to protect the threads. Some had their ends enlarged or reduced in diameter, in a device called a "setup machine." Some were coated inside with a rust-proofing compound, others were painted on the outside, and some received both treatments. Electrically welded pipe had to be annealed; that is, the stresses created by cold bending of the strip during manufacture had to be relieved by heating them in a furnace, then allowing them to cool slowly. And all pipes, before shipment, had the name "Corcoran Pipe Company" stencilled on them in white letters, and were bound with heavy wire into bundles.

Diagnosis

Arthur Ellis, continuing his discussion with John Corcoran, gained the impression that, while volume had increased since the plant was built, and the product mix had changed somewhat, present production needs were still within the capacity of the plant. He discovered, however, that the finishing operations were completely unscheduled. The only schedule produced was for the pipe mills themselves, after which pipes progressed through the finishing department on a "first-come, first-served" basis. Arthur concluded that this lack of scheduling was almost certainly a prime cause of the problems that were worrying John Corcoran. Since Arthur himself had little knowledge of scheduling techniques, he recommended that John talk to a colleague of his, Wilfred Whipps, who worked for the management services division of Arthur's firm.

They contacted Wilfred and arranged for him to visit the plant the following week. On his first visit, Wilfred asked to be given a tour of the plant. John called in Bill Howell, the superintendent of the finishing department, to conduct the tour.

Wilfred commented almost immediately on the large amount of in-process storage space dotted about the plant, some of which was almost empty, while some was overflowing. Bill explained as follows:

"Well, we need that space because my machines can't always keep up with the mill. Take that pile of six-inch pipe over there. The number 3 mill has been running that off for three and a half days now, and it keeps on coming. It all has to have both ends screwed, and that's a slow job on pipe that big. That'll take a week to clear—maybe more than a week—because I've got a couple of urgent jobs that I'll have to retool one of the screwing machines for. Same thing happens with the other machines—week after next, it might be the spray booth that's jammed up, though right now there is very little work for it. Still, that's the way my job is. Joe (Joe Newberry, the mill superintendent) can't keep changing his mills every five minutes, so they pay me to move things along just as fast as I can in the finishing department."

Later, Wilfred talked to Joe Newberry about the scheduling of the mills. He learned that the plant always "made to order," except in rare cases when business was slack and some inventory of the most common sizes and types of pipe was built up. Orders were accumulated over a two-week period, classified by size and type. These orders were then scheduled onto the mills in such a way that orders for a similar size and type of pipe were grouped together to minimize the number of times the mills had to be changed. For each mill, a list was made of all the orders it would process in coming weeks, and this list was the only schedule used. At the time, this procedure resulted in a schedule varying from four to five weeks ahead, which gave ample time for the purchasing department to buy the necessary sizes of steel strip. Job tickets were made out for each order and bore various information including the week each order was to be made on the mill. These tickets were issued to the finishing department. A card-index file of such orders was its central source of processing instructions. Also, a copy of the job ticket was placed just inside the end of one pipe in each batch, and held there by a spring clip, in order to identify the batch.

Wilfred was told that the mill schedule, once set, was very rarely changed. Joe felt that with a current delivery time of 12 to 14 weeks, the week or two gained by inserting a "rush" order could not justify the necessary size changes on the mill. Thus the mill's actual output was very close to the schedule, unless some unexpected delay held up production and caused the schedule to be moved back a day or two.

Later on, back in John Corcoran's office, Wilfred observed:

"John, I think Arthur is right that the lack of proper scheduling in the finishing department is at the root of your problems. Your mills are producing pipe on a schedule that is ideal for the mill itself, but with no reference at all to the load being put on the various machines in the finishing department. This is a prime cause of the delays and bottlenecks you're getting. If you scheduled the whole plant as a unit, instead of favoring the mills exclusively, you'd reduce a lot of the delays. There is another benefit too. You show just over two million dollars worth of in-process inventory on the books, but this is valued at material cost only. In terms of the material cost plus the value of the work you've put into it, you may have as much as five million dollars worth. An efficient scheduling system might cut that by as much as 40 percent.

"There's one thing that puzzles me, though. Both Bill and Joe talked of changing size on the mills as if it were a cardinal sin. Everything seems to be set up to keep changes to a minimum; yet, I watched your men change size on number 2, and it only took fifteen minutes including checking the new pipes as they came off until the setup was right."

John replied:

"Both these things are historical, Wilfred. In the old days, when both Bill and Joe started working for my father there wasn't much finishing. Most pipes went out plain. So the mill was the only important piece of machinery we had, and the fellows still tend to regard it that way. You may have noticed that Joe lords it over Bill, though I think Bill has a much tougher job, and has to be smarter than Joe to get it done well. Bill also supervises three times the number of men. Again, 20 years ago, it took half a day to change size on a mill. That didn't matter too much—you didn't change very often—there wasn't the variety there is now. But you avoided changing whenever you could, and that attitude persists today even though modern equipment is designed for fast changes.

"Those guys still have a lot going for them, though. You figure it out: We can run about 6,000 feet of pipe an hour, on average, or 1,500 feet in fifteen minutes. At 20¢ a foot, that's $300 in sales we lose every time we change. It's not the same in finishing—if we don't get the stuff out this week, we'll get it the next. But time lost on the mill is gone forever."

Wilfred thought for a moment and then replied:

"Well, I see your point, John, though I can't agree that delays in the finishing department cost you nothing. You're likely to lose customers, for one thing. And each time you change a screwing machine, for example, you have to pay a guy to do it, and keep all your overhead going while he does it.

"Still, the main point is that I'd recommend a new scheduling system. If you agree, I'd be happy to make you a formal proposal for the job, and give you a better idea of the benefits you should get from it."

John seemed pleased, and remarked:

"I don't think we need a formal proposal. Actually I've been nosing about the plant myself with this in mind, and I've read a couple of books on the subject, too. I quite agree that we're doing a lousy scheduling job. I'm particularly impressed that an inventory reduction of as much as two million dollars might be possible. Give me an idea of the range of the fee and then go ahead. See if you can get us sorted out before our delivery time gets stretched to twenty weeks."

Wilfred replied:

"Fine. I'll prepare an engagement memorandum outlining the scope of the engagement and the estimated fee for you to approve. Then we can get started next Monday."

The Study Phase

As soon as the engagement memorandum was approved by John Corcoran, Wilfred started. His first action was to instruct his assistant, Clive Cawthorn, to gather the necessary information about plant operations. Meanwhile, he advised John Corcoran to hire a qualified man to act as production scheduler for the company. He wanted this man to participate in the designing of the system, so that he would have a better understanding of it once he began to run it. Moreover, this would save Corcoran Pipe money, since the man could help with some of the study work that would otherwise have to be performed by the consultant.

Meanwhile Clive checked first on product specifications. He found these were simple and well-documented. The necessary information was recorded in a standard manner such as the following:

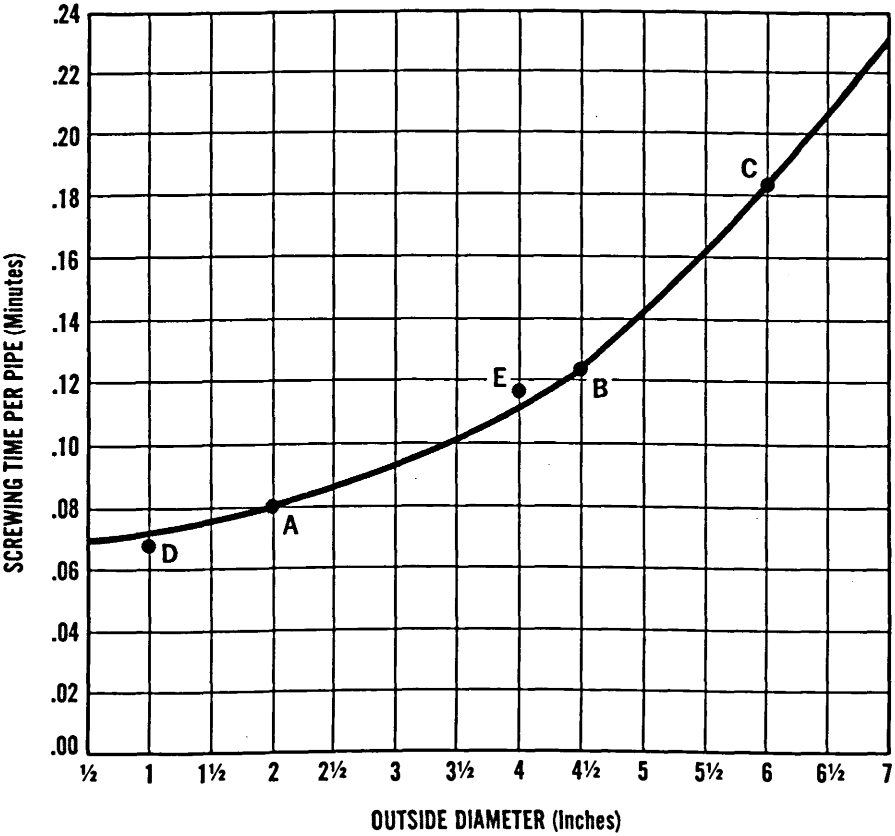
PROCESS	O.D. (IN.)	WALL THICKNESS (IN.)	LENGTH (FT.)	END TREATMENT			COATING	
					CONNECTORS	PROTECTORS	INSIDE	OUTSIDE
E.R.W.	4¼	.210	30	SCREW	X	—	BITUMEN	—

However, Clive found that the only process times available were for production on the mills. While Bill Howell, the finishing foreman, had an intuitive idea of how long each process took, he had difficulty in converting these ideas into figures. Clive therefore decided that he would have to time each of the finishing processes. He was somewhat discouraged by the magnitude of this task, since each size of pipe required a different time on each process. However, he hit upon the idea of studying just a few sizes on each process, and interpolating times for the sizes he had not studied. He took the times for three or four different sizes of pipe on each process and drew a graph of them. Exhibit 1, below, is an example. Finding that a 2-inch pipe took .08 minutes to screw, on average; a 4½-inch pipe took .124 minutes and a 6-inch pipe, .182 minutes, he plotted these points on a graph as points A, B, and C. He then drew a smooth curve through these points, from which the times for other pipes could be determined. For example, Exhibit 1 shows that a 3-inch pipe would take .094 minutes.

Clive then checked his assumption by taking a few operation times for other sizes, and comparing them with his graphs. For example, a 3-inch pipe actually took .097 minutes to screw. Points D and E on Exhibit 1 show two other sizes that he checked.

EXHIBIT 1 **Operation Time Graph**

OPERATION: SCREW PIPE END (Setup Time: Constant; 12.0 Minutes.)



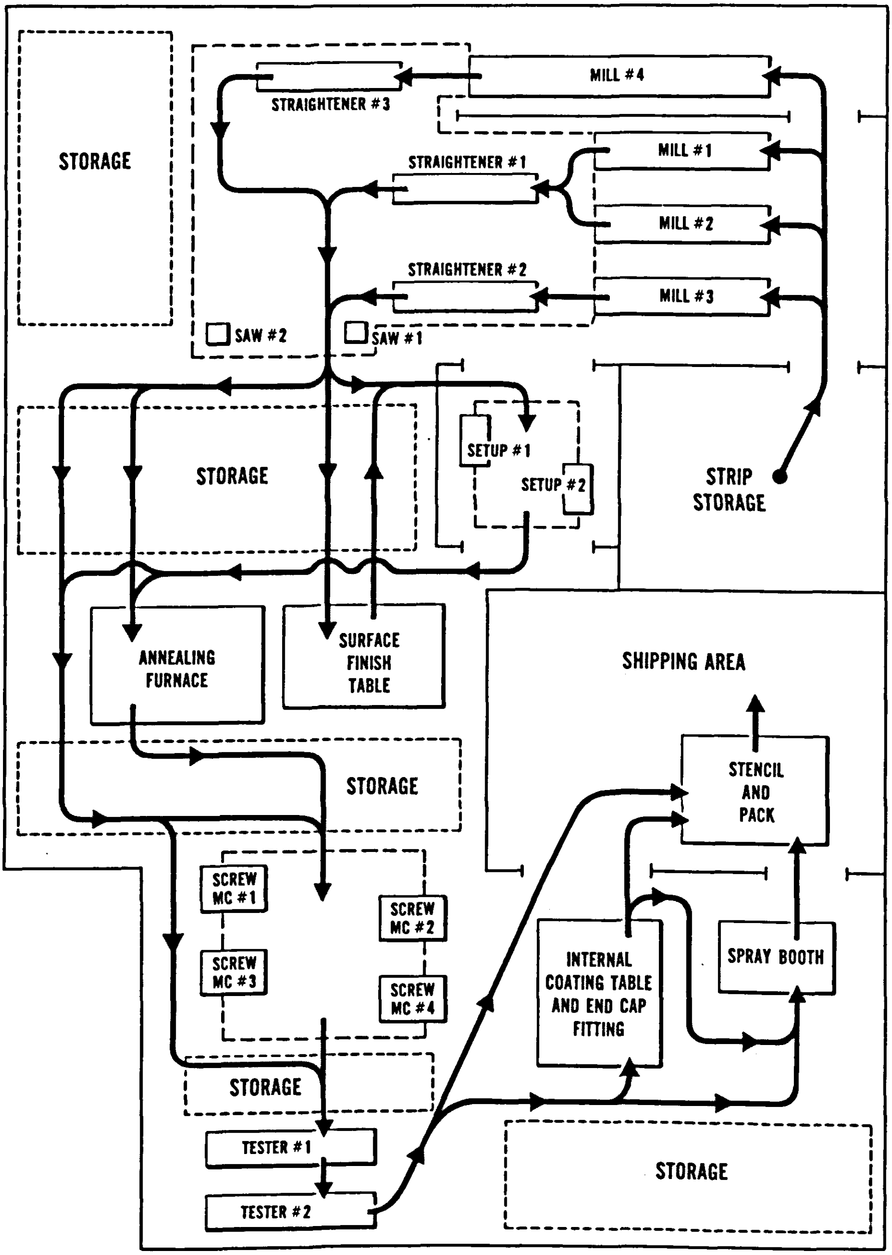
In general, he found that his estimates, while not exact, were adequate for the purposes of determining machine capacities and scheduling. There was, however, one exception. After being made, straightened, and cut to length, pipes were inspected for outside surface finish. Those with minor surface defects were diverted to a station where the defects were removed by a team of three men, using hand grinding-machines. Clive could not establish meaningful average times for this operation during the two weeks he spent in the plant, since the time varied widely and was not related to pipe diameter. However, by studying the records of the number of pipes diverted for surface finishing, and comparing them with the time-cards of the men employed on this job during the previous six months, he was able to arrive at an average time, unrelated to pipe size, that he hoped would be adequate for scheduling purposes.

The other task Wilfred Whipps had assigned him was to draw a plant layout indicating the work flow of pipes through the plant. After discussions with the finishing superintendent and his foremen, Clive was able to prepare the flow chart shown in Exhibit 2, page 63. Although this was a "composite" chart, showing the route taken through the plant by the pipes in general, rather than any particular size and type of pipe, Clive felt it would be adequate, provided it was thus qualified:

1. Pipe that passed through the "setup" machines (which swelled or shrank the ends of the pipe) was never threaded.
2. All electric-welded pipe was annealed, but hot-welded pipe was never annealed.
3. Pipe that was screwed always passed over the "internal coating table" to have either connectors or end-protectors fitted.
4. The order of operations could be varied somewhat. For example, pipes could be sent through the setup machines after annealing, or might be hand-finished on the surface-finish table after other finishing operations. However, pipes always followed the sequence of mill, straightener, saw, and always had to be tested before coating and endcap fitting, but after all other operations.

Clive noted that pipes were transported between some machines by rolling over inclined racks. All the other movement was accom-

EXHIBIT 2 Flow Diagram



plished by overhead gantry cranes, which lifted the pipes in batches. The cranes could pass over all machines and internal walls even when loaded. After observing their movements for some time, Clive concluded that transportation was adequate for normal production loads.

Clive then returned to his office to discuss with Wilfred the design of a suitable scheduling system. Wilfred felt, however, that there was one more step needed and remarked to Clive:

"You've done a good job of data-gathering and analysis. However, there is one more thing. The basic problem the company has is that scheduling is presently done solely for the benefit of the mills, with no reference to the finishing department's problems. Yet everyone, including Bill Howell, thinks that's the way it should be. Any overall scheduling system we come up with is going to cause more size changes in the mills. To the plant people this would be almost sacrilegious. Somehow we've got to convince them that mill changes aren't necessarily bad if changes help solve problems in finishing."

Clive replied:

"Yes, I see your point—it could make things difficult unless we can convince those guys. I guess I'd better get back to the plant and work out the cost of mill changes and compare that with the savings in reduced inventory, overtime, and so on. I'll check how many orders are cancelled because of delays, too."

Wilfred agreed:

"That's a good idea, Clive. It would make useful support for our proposals, if the savings prove substantial. And, of course, while we're pretty sure they will be, we'd better check before we finalize the scheduling system design. One other suggestion—talk to a couple of the salesmen. The orders they can't secure in the first place because of their long delivery times might be much more significant than cancelled orders."

Clive was accompanied on his return to the plant by Jack Holmes who had been hired by John Corcoran to operate the new scheduling system once it was installed. Jack did not have previous experience in pipe making, but had worked for several years as assistant manager of the production scheduling department of a large manufacturer of pressed steel panels and fittings for the automobile and appliance industries. Both John Corcoran and Wilfred had interviewed Jack and felt he could apply the experience he had gained to the pipe-making business, once he had learned its basic technology.

The two men worked out the average cost of a mill change as $95.00.

This included the wages and fringe benefits of the men who changed the mill as well as those who were idle while it was changed, and the depreciation of the idle machinery. With an average of 13 changes per month per mill, or about 620 changes per year, this worked out to a "cost" of some $59,000 per year.

Offsetting this, they found that overtime premium during the preceding year totaled $97,000. While a scheduling system would not eliminate this, they felt it might well reduce it by half. More impressive, however, were estimates of lost sales of at least $1 million per year because of slow delivery. At a 12 percent profit margin before tax, this represented $120,000 per year in lost profits. Therefore, without even considering inventory reductions, Clive felt that even if the scheduling system doubled the number of mill changes, it could still improve the Company's profits.

Designing the System

While Jack remained at the plant, Clive returned once more to his office to discuss with Wilfred the design of the new system. Both men agreed that the scheduling should begin with the preparation of a master schedule for the entire plant. They had difficulty, however, in deciding what capacities should be considered for master scheduling purposes. Clive felt that each machine should be considered, but Wilfred thought this would be unnecessarily complicated. They finally agreed that individual machines should be used, but only those machines that would be likely to cause bottlenecks.

Analysis of the pattern of orders received by the plant over the past year or two, and a comparison of these with the various machine operating times that Clive had developed, would have been a classic way to determine which operations were bottlenecks. Instead, however, Clive saved a great deal of time by judiciously questioning plant personnel as to which operations *had* proved to be bottlenecks in recent months. As a result, he decided to consider only the capacities of the four mills, the annealing furnace, the screwing machines, and the spray booth for master scheduling purposes.

Clive and Jack then drew up a table of output rates based on the normal plant operation of two eight-hour shifts per day, in broad size ranges, for each of those machines, as shown in Exhibit 3, page 66.

In designing the master scheduling system, Clive proposed that orders continue to be accumulated for a period of two weeks. The resulting work load on the mills, arrived at by multiplying the number of pipes ordered by the output rates in Exhibit 3, would be added to the existing backlog on the mills. This would also be done for the annealing furnace, the screwing machines, and the spray booth, making due allowance for the lead-time between pipes leaving the mill and reaching these machines. The master schedule thus produced would be in two forms: for each machine—a list of the orders it was to process in each week ahead; and for each order—a note on the job card listing the week in which it was to be processed on each bottleneck machine.

Clive realized that this master schedule would contain many approximations, notably the one that assumed that the mills would operate only within the size ranges he had chosen. He was well aware that this would not always be true in practice, but felt that in the case of ERW pipe which could be made in two alternative mills, the actual choice could be made when the detailed schedule was drawn up.

EXHIBIT 3 **Output Rates for Master Scheduling**

MACHINE CAPACITIES: PIPES PER DAY* (Based on two shifts per day)

	½" to 2" DIAMETER	2¼" to 4" DIAMETER	4¼" to 6½" DIAMETER
MILL #1	1,400		
MILL #2		1,200	
MILL #3			1,050
MILL #4	1,750	1,500	1,200
ANNEALING FURNACE	4,000	3,700	3,300
SCREWING MACHINES	3,200	3,000	2,750
SPRAY BOOTH	2,500	2,000	1,300

*Note: These output capacities were arrived at using a weighted average output rate of the sizes within each range, and then adding a factor to allow for setup time based on average lot sizes.

He and Jack now gave their attention to the detailed scheduling. Because of the importance of the relationship between mill capacity and the capacity of the finishing machines, they decided that they should find a way for Jack to visualize the relationship easily. They hoped to achieve this with a display board in the form of a Gantt chart. They also decided to schedule forward from the date each order was placed in the master schedule, rather than backward from the promise date. While they expected to increase the number of mill changes, they still wished to group orders of a common size as much as possible, and this would be extremely difficult if backward scheduling were employed.

Clive designed a scheduling board similar to the one shown in Exhibit 4, page 68. (He was able to combine some of the machines, such as the two setup machines, since they usually worked as pairs.) He proposed to use this board as follows: As each order was scheduled, cards would be cut to length for each machine over which that order would pass. The length of each card would be proportional to the time the order would take on that machine, on the same scale as the boards themselves. Each card would carry the order number and an abbreviation of the machine's name.

These cards would be slotted into the board opposite the relevant machine in logical sequence, as demonstrated (with a single order) in Exhibit 5, page 69.

It would not, of course, be possible to schedule this order for completion in such a short time once many other jobs were loaded onto the board. It would be possible, however, to see at a glance when one machine was becoming seriously overloaded, and to try the effects of various changes in the schedule in order to correct this.

The plant worked two shifts, six days a week. Normally all preventive maintenance which required the machines to be stopped was done on a third shift, so that production did not have to be interrupted. However, Clive felt maintenance could easily be incorporated in his system, if need be, by using a card of a different color and slotting it into the board as necessary.

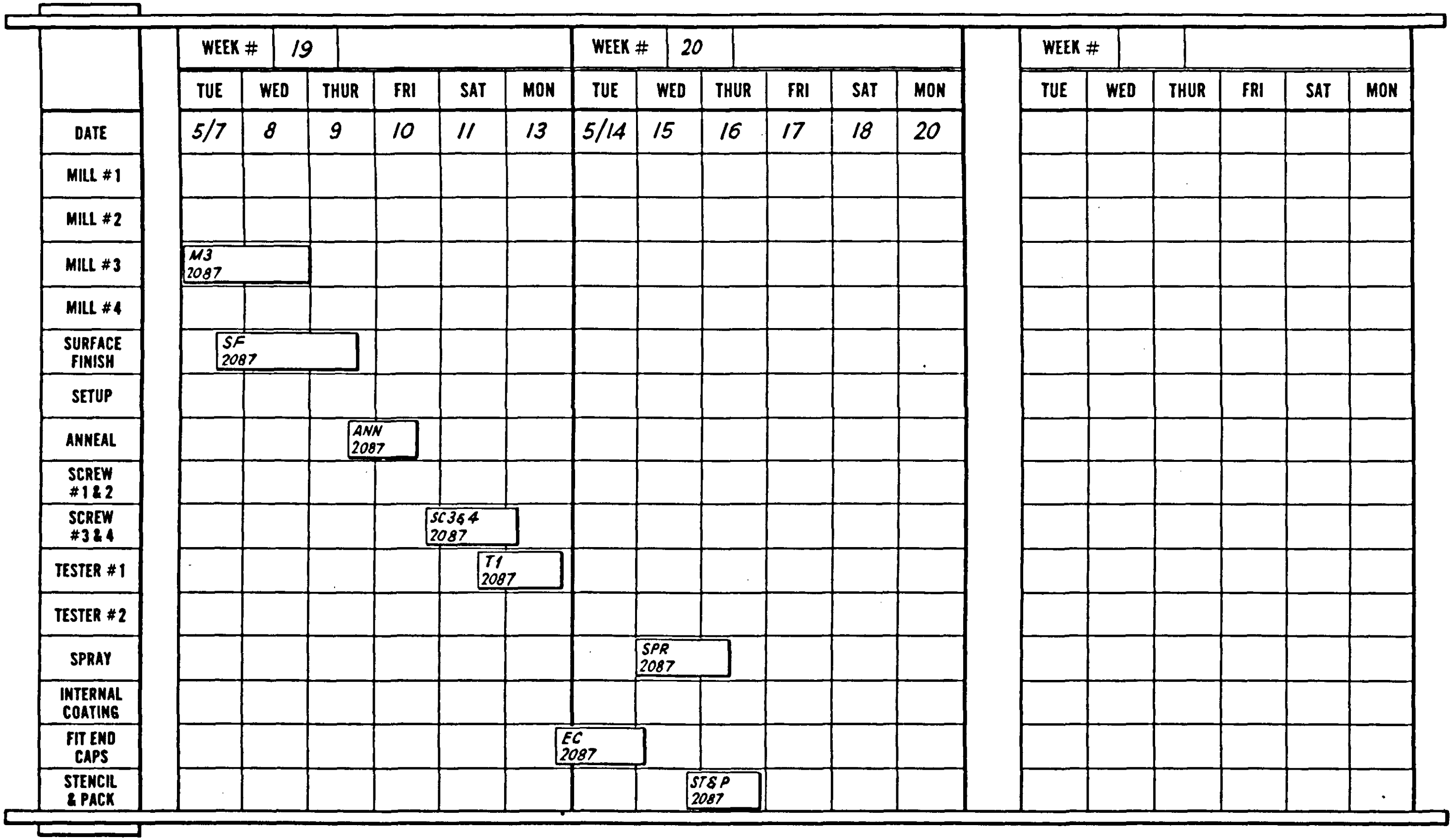
He could also incorporate overtime work, and the use of extra men to speed up jobs such as surface finishing. This would be accomplished by shortening the card an appropriate amount, and noting on it the overtime hours, additional men, or whatever other action was to be taken to speed up the job.

A list of orders to be processed by each mill each week was pre-

EXHIBIT 4 Scheduling Board

	WEEK #						WEEK #						WEEK #					
	TUE	WED	THUR	FRI	SAT	MON	TUE	WED	THUR	FRI	SAT	MON	TUE	WED	THUR	FRI	SAT	MON
DATE																		
MILL #1																		
MILL #2																		
MILL #3																		
MILL #4																		
SURFACE FINISH																		
SETUP																		
ANNEAL																		
SCREW #1 & 2																		
SCREW #3 & 4																		
TESTER #1																		
TESTER #2																		
SPRAY																		
INTERNAL COATING																		
FIT END CAPS																		
STENCIL & PACK																		

EXHIBIT 5 Scheduling Board Carrying Order # 2087



	WEEK # 19						WEEK # 20						WEEK #					
	TUE	WED	THUR	FRI	SAT	MON	TUE	WED	THUR	FRI	SAT	MON	TUE	WED	THUR	FRI	SAT	MON
DATE	5/7	8	9	10	11	13	5/14	15	16	17	18	20						
MILL #1																		
MILL #2																		
MILL #3	M3 2087																	
MILL #4																		
SURFACE FINISH	SF 2087																	
SETUP																		
ANNEAL			ANN 2087															
SCREW #1 & 2																		
SCREW #3 & 4					SC3&4 2087													
TESTER #1					T1 2087													
TESTER #2																		
SPRAY								SPR 2087										
INTERNAL COATING																		
FIT END CAPS						EC 2087												
STENCIL & PACK									ST&P 2087									

pared from the board. This, and not the master schedule list, would be issued to the mills as their processing authority.

Instead of the single job ticket now given to the finishing department, Clive designed a ticket for each machine. This would also be marked with the week in which that particular order was to be processed on that particular machine (which would usually, but not always, be the same week as had originally been planned in the master schedule). These cards would then be stacked for each machine, the stack being in the same order as shown on the board. This stack would form the processing instructions for each machine. At the end of each day, the foreman would be responsible for returning to the scheduling department the cards for all completed work, thus providing Jack with the feedback on progress that he needed.

Clive felt that separate instructions were not needed for the overhead cranes. At present these were "controlled" by a man on the ground (who also hitched up and unhitched the loads) through voice and signals to the crane driver. This system was causing no serious delays at present, and would work even better once work-flow improved and inventories were reduced.

It was decided that the plant should schedule one week ahead as firm, and two additional weeks as tentative. Clive realized that if Jack began a scheduling week on a Monday, the new schedule would have to be fairly firm by midday Friday, since Jack was not expected to work weekends. This was not always possible, however, since a Monday to Friday schedule might be out of date on Monday morning, if production on Saturday (and Sunday, if overtime was worked) had not gone according to plan. On the other hand, if Jack made his plans early in the week, overtime could be used at the weekend to "rescue" the situation if the schedule went awry. Jack and Clive discussed this and decided to run on a scheduling "week" of Tuesday to Monday. The day before each such week—i.e., on Monday morning, he would devise his one-week firm schedule on the planning board, and discuss it with the two superintendents. On Monday afternoon he would make whatever changes resulted from this meeting, and a clerk would start preparing the written schedules and job tickets. The firm part of the schedule would thus be ready to go into operation the following (Tuesday) morning.

On Tuesday morning, Jack would be left with one firm week, one tentative week, and one blank week—the one that had just been completed. Clive had designed the board so that each one-week section was separate, and could be slid along laterally in grooves (see Exhibit 4). The blank section could therefore be removed from the left-hand side of the board and reinserted at the right, without disturbing the other two sections. Jack could extend his tentative schedule for a further week on this blank section.

On Thursday afternoon he would meet again with the superintendents to discuss the next week's tentative schedule, as well as any serious deviations from the current schedule. On Friday he would make whatever schedule changes had been agreed upon.

Clive and Jack felt that they had sufficient information and ideas to make a presentation to Mr. Corcoran, and Wilfred Whipps agreed with them. A meeting was therefore planned for the following week.

Questions

1. Do you think the consultants were right to accept John Corcoran's suggestion that they proceed to design a new scheduling system with no more investigation than a plant visit by Wilfred Whipps? If not, what further study would you suggest?
2. Do you feel that Clive gathered the right information before designing his system? If not, what other information would you have gathered? What would you have left out?
3. Clive had trouble arriving at operation times for the surface finishing of pipes. Are you satisfied with the way he solved the problem?
4. If you were Joe Newberry, would Clive's arguments in favor of an increase in the number of mill changes convince you?
5. What is your opinion of the master scheduling system envisaged, in terms of:
   a. Basing it on machines that plant personnel considered bottlenecks?
   b. The approximations involved?
   c. The resulting "broad-brush" schedule produced?
6. Is a Gantt chart type of display board the best means of detailed scheduling for this particular application?
7. Do you think the scheduling system will work? Explain.
8. Jack, Clive and Wilfred now feel they have sufficient information for recommendation to John Corcoran. Do you agree?

The Proposal

On February 28, 19...., the two consultants and Jack Holmes met with John Corcoran and his two shop superintendents. They presented their arguments in favor of their new scheduling system, then went on to explain it in detail.

Clive had prepared a small cardboard version of his proposed scheduling board and used it to demonstrate how Jack would maintain his schedule. In particular, he demonstrated that, while the mills would have to change sizes more often, this would actually reduce overall operating costs. He pointed out that, while Jack would have overall responsibility for the schedule, the two superintendents would have to implement it, and therefore would work with Jack in producing it.

Joe Newberry appeared to be visibly upset, but agreed to give the proposal a try. The other company personnel appeared enthusiastic.

Reorganization

After Joe and the other company personnel had left his office, John Corcoran chuckled, and remarked to Clive and Wilfred:

"Joe seemed somewhat upset, Clive, but he's like that—a little temperamental. Don't worry, he'll become more enthusiastic in time. I've got some questions about your scheme, but basically I'm in favor of it."

Wilfred frowned and replied:

"I'm not sure it's that simple, John. Joe has made me realize what I should have seen before. Up to now he's been "king" of the plant, and now we're proposing that, in a sense, Jack should tell him what to do. Naturally, he's upset that his influence is being reduced, especially by a man half his age who has only been with the company two weeks."

John answered:

"Sure, I understand how he's feeling, but he's a reasonable guy and very loyal to the company. He'll come around once he sees that the scheduling system is working."

Again Wilfred frowned and replied:

"That's just the problem, John. Unless he sincerely supports it, the system won't work. No system, however good, can work unless the people running it are behind it. We've got to find some way of getting him on our side before we start. It's late now, but let's give some thought over the next week or so to how we can do that."

Later, as a result of various discussions among the people involved, it was decided to give Joe the title of Production Manager. One of his mill foremen was promoted to mill superintendent, and both he and Bill Howell reported to Joe. Bill seemed quite agreeable to this arrangement, saying that he felt this had always been the real situation in any case. Joe and Jack were on equal footing, both reporting to John. While Joe seemed happy about these changes, it was agreed that John would sit in on some of their initial meetings to discuss the detailed schedules and to resolve any shop difficulties being experienced.

Implementation

The program of implementation now began. John had a board made up to Clive's specifications, and placed in a small office next to Mill #4. Jack was given the part-time help of a clerk to assist him with some of the detailed work of cutting out cards for the board, typing up schedules, and so forth.

The first stage of implementation began on March 26th. Jack proposed to leave the schedule as it was for the following three weeks, but during this time he converted the existing "old-style" schedule to the new master schedule by adding the information required for the three finishing operations that were bottlenecks. Then he used the operation times Clive had derived to predict what the detailed state of affairs in the plant would be by April 16, the first day the new method of scheduling would actually be used. Having done this, he entered the schedule on the display board. As April 16 approached, Jack watched the progress of work in the shop, and adjusted his proposed schedule accordingly. When April 16 finally arrived, he was able to put the system into effect throughout the shop.

The period between March 26 and April 16 had given Jack an opportunity to demonstrate to Joe the effects of various ways of scheduling, and, in particular, differences between the old and the new practices. After a period, Joe began to be more and more enthusiastic about the new system. While it did increase the number of mill changes, he could see the benefits of this in the finishing department (now also his responsibility).

Clive watched the implementation stage closely. After four or five weeks he was satisfied that it was going well and left for another assignment. He, of course, checked frequently to be sure that unexpected problems did not develop.

Engagement Evaluation and Follow-up

Three months later he returned to the Corcorn Pipe Company to review the status of the system. He met with an enthusiastic John Corcoran who remarked:

"Clive, you did a great job for us. Since the new system went in, our inventory of work-in-progress has dropped significantly, and I think we can still reduce it a bit more. I've been able to move three of Bill's assistants to other jobs—previously they'd been doing nothing but chase delayed and lost orders. Our maximum backlog now is nine weeks, and most of the orders are getting out faster than that. I'm particularly pleased since most of them are getting out when we promised the customer they would. All in all, I'm more than satisfied."

Bill and Joe were also enthusiastic about the new system. Bill, in particular, was finding his job much easier, and was experiencing a substantial reduction in costs. Not only were there less man-hours wasted in idle time and in "fighting fires," but Bill now had the time to implement some cost-reduction ideas that he had had in mind for several years.

Jack, however, had some reservations and outlined these to Clive as follows:

"Clive, there is no doubt that in the main the system is working well, and has improved things around here a great deal. It's not perfect though. On a couple of occasions the surface finishing has given us trouble. For weeks we'll run just fine, then we'll get a bad batch of strip, or there'll be a problem on the mill, and suddenly 50 percent of the pipes being produced, instead of the usual 5 percent, have to go for surface finishing. As a result, that particular order is held up, the machines that are waiting for it stand idle or have to be changed to another size, and I have to run around like a scalded cat trying to rearrange the schedule. Frankly, I don't see how to lick the problem, and I can't allow for it in my normal schedule, because it's unpredictable."

Clive, too, was somewhat puzzled as to how to solve this problem. He felt that Jack was using the best short-term solution: rearranging the schedule. But he wondered if there might be a better answer. He thought about the possibility of using waiting-line theory, but wondered if the "arrivals" of pipes to be dressed were really random. In any case, while waiting-line theory might indicate the optimum staffing level, it would not help with the week-by-week scheduling. Clive decided to return to his office to discuss the problem with Wilfred.

Clive explained the problem to Wilfred, who had these comments to make:

"I think this is more complicated than it sounds, Clive. Basically, of course, it's a quality control question rather than a scheduling problem, and one angle of attack is to treat it as such. You've explained that these surface defects aren't normally visible in the strip until bending it into a tube opens them up. However, there must be other ways of checking for them by eye, and we'll get John to investigate them. It'll probably not be possible to eliminate the problem entirely, though, so we'll have to find a way of handling it once it occurs. Much of the problem seems to be a question of capacity. Normally, we have three men on surface finishing and they can keep up with the work load until we get a problem. Then suddenly we need fifteen men. If we can figure out a way for John to find those fifteen men whenever he needs them, we've licked the problem."

It was John himself who thought of the solution to the quality control aspect. Coils of steel strip were inspected on arrival, but often the small surface defects were not visible. They opened up later, when the strip was bent into a tube. John therefore installed a small mechanical shear and a bending machine in the coil storage area. Each coil delivered now had a small section cut from it, which was bent to form a short pipe. If the surface then showed defects, the coil was returned to the manufacturer as defective.

Poor surface finish could also be traced to faults on the mill, especially damaged rolls. Joe had to be convinced that it was cheaper to stop the mill for a few minutes and correct the fault than to pile up dozens of pipes that needed expensive hand finishing.

Once he had been convinced, and the technique of inspecting coils had been improved, the number of pipes needing surface finishing dropped to less than half. To alleviate the occasional crisis that still occurred, several groups of plant maintenance men, particularly sweepers and machine greasers, were trained to do the work. Since it paid a higher rate than their normal one, they were more than willing to do this.

This reservoir of labor, augmented by the use of overtime, meant that, although crises still occurred at times, they could be cleared quickly, with a minimum amount of rearrangement of the schedule.