PRODUCTION-LINE TECHNIQUE

*This book is produced in full compliance with the government's regulations for conserving paper and other essential materials.*

# PRODUCTION-LINE TECHNIQUE

*by* Richard Muther

*Department of Business and Engineering Administration, Massachusetts Institute of Technology*

*With a Foreword*

By Erwin Haskell Schell

First Edition
Second Impression

McGRAW-HILL BOOK COMPANY, Inc.
NEW YORK AND LONDON
1944

PRODUCTION-LINE TECHNIQUE



PRINTED IN THE UNITED STATES OF AMERICA



THE MAPLE PRESS COMPANY, YORK, PA.

## ACKNOWLEDGMENTS

It was Mr. B. Edwin Hutchinson of Detroit who, as a member of the Corporation of the Massachusetts Institute of Technology, first initiated interest in the preparation of educational material devoted to production-line methods. Throughout the ensuing studies and field researches, which formed the foundation of the present book, his assistance in making available important data and in establishing authoritative contacts has been invaluable.

The cooperation of production men representing more than one hundred industrial establishments is most appreciated. These individuals and their organizations gave freely of their time and without reservation made available their detailed procedures. The present text results largely from their contribution. Only space prevents the expressing of our thanks to each.

For the conduct of auxiliary field investigations and the contribution of special sections of the manuscript, credit is given to the students in line production at the Massachusetts Institute of Technology, including members of classes who submitted theses or project data and industrial executives who participated in the initial discussions for which the prepublication notes were employed as a text.

The work of Professor Ronald H. Robnett and Mr. W. Van Alan Clark, Jr., deserves special acknowledgment, and the services of Mrs. Sherley Kempster, Miss Esther Merrill, Mrs. Margaret Richardson, and Miss Beatrice Rogers in the collection, organization, and preparation of material are particularly appreciated.

Throughout the entire investigation and arrangement of the material, the guidance of Professor Erwin H. Schell has been of direct assistance. His analysis, organization, and constructive review of the manuscript are chiefly responsible for whatever contribution this book may make.

CAMBRIDGE, MASS.,
*January*, 1944.

RICHARD MUTHER.

# CONTENTS

# FOREWORD

American industry has contributed to the war effort in an infinite number of ways. Among the most important of these has been the application of production-line techniques. Largely by means of such methods, high-precision products were manufactured in rising volume that far exceeded expectations.

It is the opinion of industrialists who have recently applied these methods that ensuing years will see continued growth in their application to plants hitherto operating on a job-lot basis; and it is to these manufacturers, for whom line production is a relatively new undertaking, that the text is directed.

Mr. Muther has given the better part of two years to gaining firsthand information concerning these techniques in manufacturing establishments in the Detroit area and elsewhere. His observations have been made first as an operator on various production lines, second as a technical staff assistant concerned with line organization and maintenance, and last as an analyst and observer of a large number of representative line installations.

His accumulated data have been tested for completeness and clarity in discussions and problem sections with students and operating executives who comprised three classes in a course in line-production methods, where the material has passed through revisions in note form. His presentation is at once objective and penetrative and from the beginning has been organized for the express purpose of assisting in the practical application of these procedures to the medium-sized establishment.

For the first time, industry now has available an authoritative portrayal of the principles and practices underlying this extraordinary technique, which has indeed proved to be one of the greatest contributions of the American manufacturer to the nation's security.

ERWIN HASKELL SCHELL.

CAMBRIDGE, MASS.,
*October*, 1944.

# PART I

# LINE PRODUCTION: ITS ADVANTAGES AND LIMITATIONS

## CHAPTER I

## INTRODUCTION

This book is designed expressly for usefulness to industrial executives who are considering the application of production-line methods to their manufacturing operations. It aims to picture the current state of this art found in well-established organizations whose experience with such procedures has been sufficiently lengthy to permit of the drawing of reliable conclusions. More particularly, the purpose is to present the possibilities of the production line in the medium-sized plant, which until recently has been the accepted domain of job-lot manufacturing.

**Chapter II, Line Production.**—Line production is a kind of manufacturing that is sharply distinguishable from other forms. While it appears in a variety of applications, there is always a clear conformance to certain basic definitions. The second chapter outlines these characteristics and tells something of the early beginnings of the method, of its current development, and future significance.

**Chapter III, Advantages and Limitations.**—The production line has its place. More than this, there are important prerequisites to be satisfied before such installations may be depended upon to provide satisfactory results. In order that the reader may be in a position early to judge of its possible applications, a considerable number of specific examples of success and failure in its introduction and operation are presented in this chapter.

**Chapter IV, Methods and Equipment.**—This chapter is the first of five chapters devoted to the establishment of the production line. Here we have an opportunity to learn of the work of the processing engineer and his relationships with the tool designer and other production specialists. We also see the sequencing of activities as the original design is altered to take greatest advantage of line-production economies and as the design is released, the components arrayed, the exact processes and equipment determined upon, and the operations lists prepared.

**Chapter V, Movement of Materials.**—Line production views transport to be of equal significance with operation. The handling devices used, the transport of continuous streams versus groups of parts, the use of transporting equipment as holding devices at operation points, the even or intermittent movement of the line, the introduction of control instruments—all these aspects of material movement which are vital to the success or failure of the installation are given consideration in this chapter.

**Chapter VI, Layout.**—To the onlooker, layout may appear to be the major element in the organization of the production line. While other factors are no less important, it is true that upon layout depends much of the final effectiveness. More important, defective layout may curse a line sequence from its establishment and render efficient operation impossible. The sixth chapter tells of the differences found in layout for fabrication and layout for assembly and indicates the effect of buildings and equipment upon layout. The characteristic varieties of arrangement are also described and compared.

**Chapter VII, Balance.**—Extraordinary ingenuity is displayed in this activity of balancing the line, a responsibility unique to line production. Reserves in the form of banks or floats may be found desirable; operators may be moved about; operations may be combined, subdivided, or improved. Field studies have revealed several methods by which line balance may be visualized. These procedures are described in this chapter.

**Chapter VIII, Installation.**—The last step in the establishment of line production is that of completing the technical details of installation and turning the line over to the production-department executives. The experience of organizations in using outside contractors versus their own employees at this and earlier stages, the nature of line tryout, and case studies of actual transitional sequences are dealt with in this chapter.

**Chapter IX, Organization and Planning.**—This chapter opens the third section of the book, which is concerned with the operating features of the production line. The organization for this method of manufacture differs from job-lot production in both form and emphasis. Extraordinary attention is paid to facilitating and supply activities, with less weight frequently placed upon the responsibilities of the operating executive. Other functions vary sharply in importance as the line takes the place of the lot. Responsibilities of top management also show points of variance, and the planning function takes on new and increased significance, as examples from several establishments tend to indicate.

**Chapter X, Materials Control.**—Many observers of line production maintain that it is in materials control that this procedure varies most radically from other methods of manufacture. The emphasis in line production upon continuous and established rates of flow brings new requirements affecting relationships with suppliers, extent and location of materials reserves, expediting, intrafactory handling, and the storage of parts or assemblies. Chapter X deals primarily with these techniques.

**Chapter XI, Production Control.**—Simplicity is the keynote of production control in the typical line-production plant. Yet there are certain control requirements the satisfactory accomplishment of which is vital to successful line operation. A new relationship between batch operations supplying the line, known as *cycling*, here appears. These aspects of production control, together with certain distinctions between fabricating-line control and assembly-line control, form the content of this chapter.

**Chapter XII, Quality.**—While interchangeability of parts is a principle of assembly manufacturing that antedates the spread of line-production techniques, it is a fundamental part of these methods and an inescapable prerequisite to their operation. Yet high precision is not held to limit the possibilities of line production. In this chapter these aspects of quality are discussed, and consideration is given to problems of inspection at receiving points as well as along the production line, of repair methods, and of salvage activities.

**Chapter XIII, Maintenance.**—New responsibilities resulting from the closely dependent operation sequence found in line production bring changes in maintenance organization and procedure. This chapter describes these requirements, providing specific suggestions for servicing the line and for caring for breakdowns.

**Chapter XIV, Personnel.**—Few aspects of line production are more significant than those relating to production-line personnel. To achieve high-volume, high-precision output with untrained and relatively unskilled labor has been one of the crowning achievements of our war-production plants. This chapter discusses important phases of the personnel relationship with particular reference to employee and union attitudes, worker selection, training, transfer, and the use of incentive plans. An unusual feature here is the methods used for assuring the continuance of line operation in the event of operator absence or illness.

**Chapter XV, Flexibility.**—A common misconception of line production is that it is entirely lacking in flexibility. Chapter XV effectively disposes of this assumption by describing ways in which diversification of products is obtained and variations in layout, equipment, and rates of output readily cared for. The constant impact of conversions, change orders, and improvements and the corresponding methods of adjustment to them with minimum loss of operating effectiveness are also outlined here.

**Chapter XVI, Modifications.**—Line production is subject to a great variety of modifications in some of which job-lot and flow procedures are so intertwined as to make definition difficult. Combination layouts, multiproduct lines, disassembly sequences, and repair and salvage-flow layouts are some of the techniques described in this chapter.

**Chapter XVII, Case Problems.**—For the executive who anticipates the installation of line-production methods, much can be learned from the study of case problems. In this chapter are such problems drawn from actual situations found in manufacturing establishments where line production is in operation. These problems have been tested for clarity and completeness in class discussions in which engineering students and operating-plant executives actively participated.

# CHAPTER II

## LINE PRODUCTION

There are many who believe that if the United States, with its high labor costs, is to compete in world trade and at the same time meet its growing domestic requirements, more efficient production methods must be developed. One of the ways of meeting this necessity is by the use of a type of manufacture which can turn out a great many finished units at small cost. It is here that line-production methods offer greatest promise.

Production itself involves primarily the coordination of material, men, and machinery in the easiest and most effective way. Fundamentally, there are seven possible methods by which these three elements may be related:

*Moving Material.*—Material passes from one machine and its operator to another; an eyelet machine; an assembly line; the ordinary type of job-shop work.

*Moving Men.*—Operators progress from one workplace to another, performing an operation on material placed at each, or performing the same series of operations at each of several stationary fixtures.

*Moving Machines or Tools.*—Operator at a bench works on material using several tools; a turret lathe; a mobile welding machine transported to different workplaces.

*Moving Material and Men.*—Worker carries the material from operation to operation; normal toolroom practice.

*Moving Material and Machines or Tools.*—Material and tools are brought to the men; assembly or fabrication where such tools as drill jigs are attached to each moving fixture.

*Moving Men and Machines or Tools.*—Several operators, each with a tool, work progressively on the same material; scraping down a boat; cleaning sand from streets in the spring.

*Moving Material, Men, and Machines or Tools.*—This is seldom practical, although used in building construction and ship assembly.

When material, men, and machinery are all stationary, there can be no real production in a manufacturing sense.

It was long ago discovered, and is emphasized even more with modern materials-handling equipment, that it is generally cheaper to move the material than to move either the men or the machines. With either jobbing work or mass production, the operator is normally associated closely with the machine he operates, for he is skilled or trained in making it function. If the material does not move to the men and the machines, they will have to move to the material. The ordinary plant, therefore, manufactures its product by transmitting it through the shop from one operation to the next.

How, then, can this material be passed from operation to operation most effectively? One answer is to set the machines or work areas side by side in the order of the operations required to fabricate the part or to effect the assembly. It is this kind of manufacture that is termed *line production.*

## NATURE OF LINE PRODUCTION

In the orthodox method of fabrication, the equipment is grouped according to the function which it is to perform; that is, the machinery is so arranged that all equipment of one generic type is located in a certain area. Thus there is a department of milling machines, a stitching room, or a paint shop. This is known as the *functional layout* of equipment or *layout by process.* In line production, the arrangement is governed not by the function to be performed but by the product or component to be made. Instead of a drilling department, there will be a piston department or "line" which will have machines or equipment of several different types. These various machines will be arranged in sequence so that as the work progresses from one machine to the next, successive operations are performed. After passing through the final operation in the series, the component is completed. Figure

1*a* and *b* shows the comparison between functional layout and line production in fabrication.

Likewise, in assembly, normal practice is to place the principal component in a central or convenient location on the floor or bench or in a holding device. All the material is

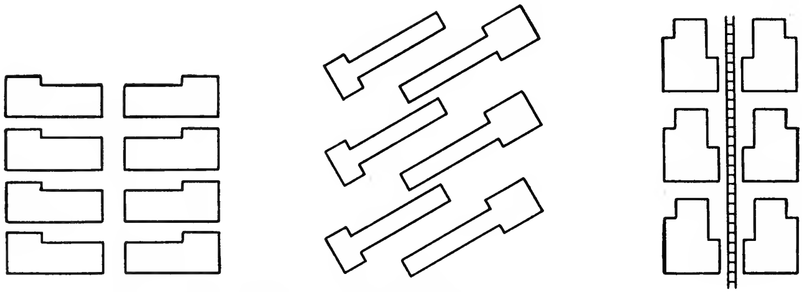


FIG. 1*a*.—Fabrication in functional layout or layout by process.

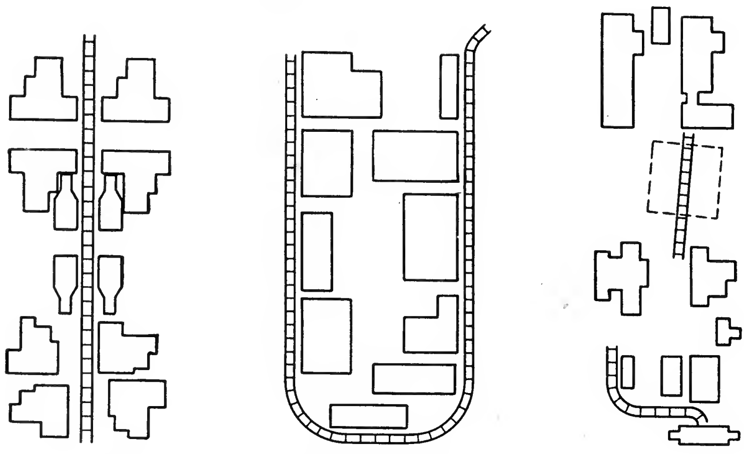


FIG. 1*b*.—Fabrication in line production or layout by product.

brought to this central erection point, and the lesser parts are attached or fitted, the principal component remaining in one place until the assembly unit is completed. In line production, on the other hand, the various parts are not brought to a centralized assembly station; rather, they are placed at an assigned series of work areas. As the chief component passes from one work area to another, these parts or subassemblies are attached. Figure 2*a* and *b* illustrates this procedure.

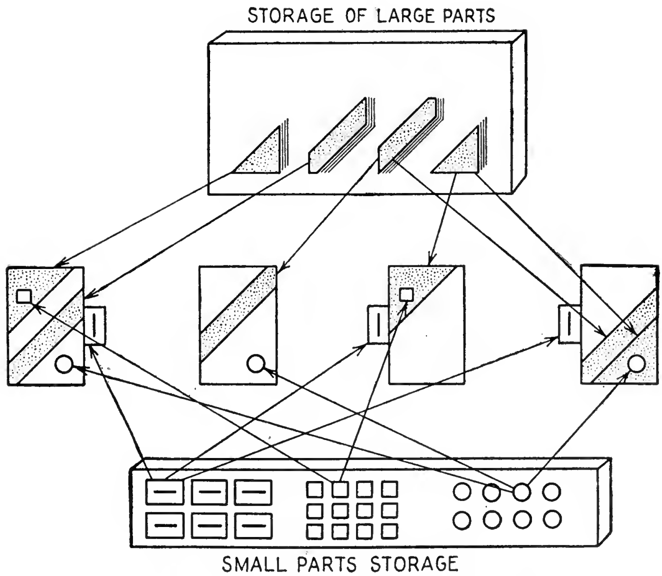



FIG. 2a.—Assembly in functional layout. When assembling in fixed location one complete assembly is made at one point. One man or crew makes the complete unit, bringing all material to each assembly.

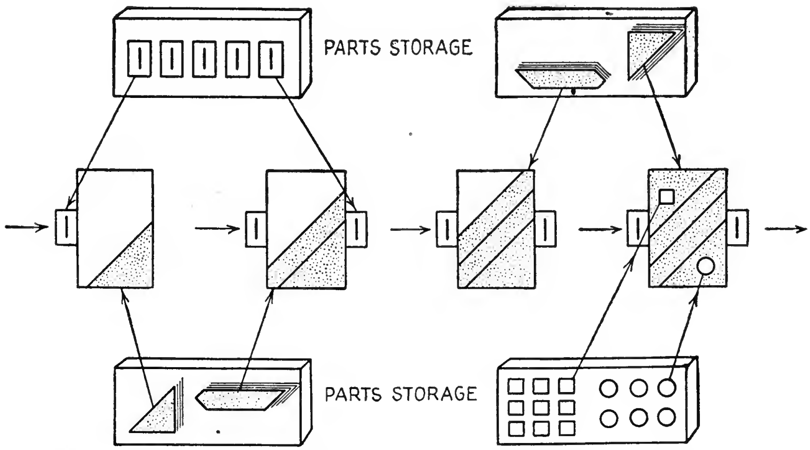



FIG. 2b.—Assembly in line production. In line production the work moves, and since like parts are located at the point of usage they are always added at the same station by the same workmen.

## DEFINITION AND EXAMPLES

Line production is a method of manufacture or an arrangement of work areas where the material moves *continuously* and at a *uniform rate* through a sequence of *balanced operations* which permit of *simultaneous performance* throughout, the work progressing toward completion along a *reasonably direct path.* Actually, the complete refinements of line production are seldom attained.

Various names for this method of manufacture have been used, and there have been confusion and misunderstanding regarding the terminology. For example, the following names have been applied to this type of manufacture:

Line production
Layout by product or product-control layout
Straight-line production
Direct-line production
Progressive manufacture
Serialized production
Flow production or flow work
Unit manufacture

The German expression is *Fliessarbeit* (flow work), while the French use *travail à la chaîne* (chain work). The term *line production* seems to be the simplest and most generally understood.

Such names as mass production, quantity production, and continuous manufacture, operation, or production are not true synonyms for line production.

There is nothing essentially new about this method of production. It has been used for at least 25 years in the manufacture of many well-known articles. Even in our everyday life we have seen examples of the serialized method. Perhaps the most common is the cafeteria. Here the chief component, the tray, moves from assembly station to assembly station, gathering food, so that when it reaches the end of the line, it carries a complete meal. The cafeteria line is not precisely like a normal assembly line; for here one operator builds up the entire unit, whereas ordinarily parts would be added by a different operator at each station. However, this example illustrates the difference between line production and the orthodox method of output.

The relation between mass production and line production is frequently misunderstood. Mass production means high-

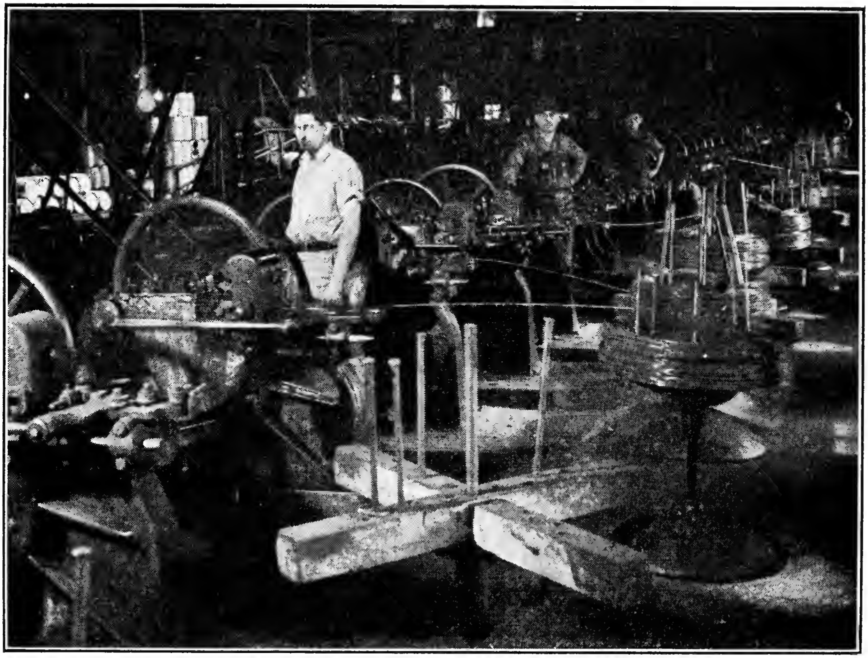


Fig. 3.—Mass production without line production is seen in this row of machines, each of which turns out 350 nails per minute. (*Courtesy of Mid-States Steel & Wire Co.*)

volume, or large-quantity, production and can be obtained from one machine in a process layout or on a production line regardless of the arrangement of equipment. A battery of automatic screw machines or a wire-forming machine making five paper clips a second are examples of mass production. Figure 3 shows such mass production. On the other hand, it is the progressive layout of work areas that distinguishes line production. The two are similar in that, for best results, line production also requires high-volume, steady production of a standardized product.

In summary, let us review the evolution of the shoemaker and his trade. Originally, he made a complete pair of shoes, employing only his own efforts, even to the extent of making his own glue and nails. Later these activities were subdivided, so that in the manufacture of shoes there was a cutting room, a stitching room, a lasting room, and a packing room. Men became specialists in these various skills and performed only one or two operations on each pair of shoes. This is a normal type of manufacture today. Recently these jobs have been further subdivided, each operator performing only one operation on each part as the material flows past his workplace. Today in certain installations there are fairly definite production lines set up for the fabrication of such components as the upper, the lining, and the sole. As these parts are finished, they are stored at assembly points along the final line for attachment when the shoes pass by. Through the breaking down of these various operations and their progressive sequencing, it has been found that output is greatly increased for the effort expended, and cost is materially reduced.

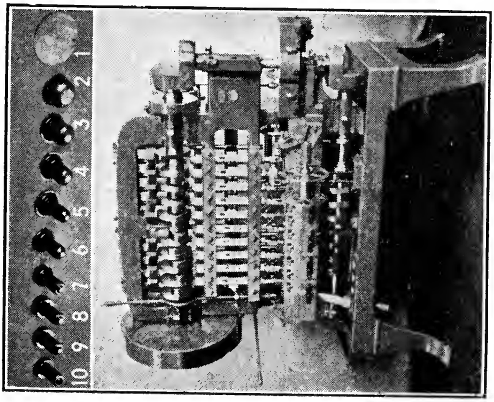
## TYPES OF LINE PRODUCTION

Line production may be achieved in the following ways:

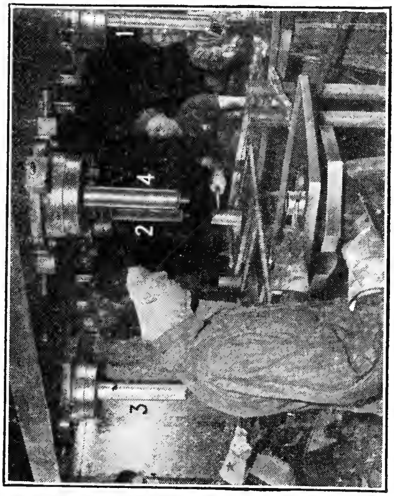
*Flow within one machine* is found in the eyelet machine (as seen in Fig. 4), a multiple-spindle automatic lathe such as the National Acme or New Britain-Gridley, or any multistation indexing machine such as the Bullard Mult-Au-Matic.

*Sporadic lines within process departments* may be seen in a series of forging presses set up to handle one primary item in a forge department, or in such processing sequences as cleaning, painting, and drying.

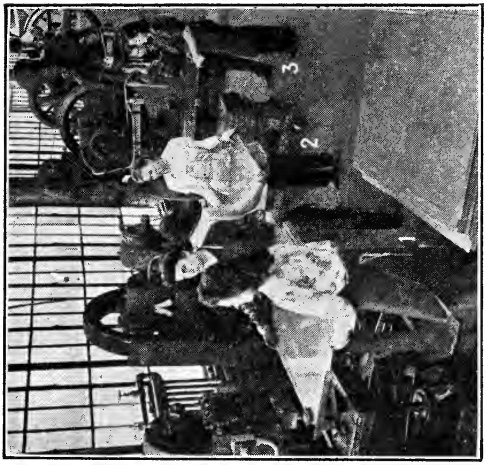
*Line assembly with job-lot fabrication* is found in the light-chemical or food industries where the product is made up in batches and packaged on a production line. Behind the majority of assembly lines lie fabrication departments laid out for job-lot manufacture.




Flow within one machine—an eyelet machine and a sample of the work in various stages of completion. (*Courtesy of Waterbury Farrel Foundry & Machine Company.*)




Flow within one machine with several operators—four stages in drawing shell cases within one press.




Flow through several machines with several operators—trim and forming operations in a common type of production line.

FIG. 4.—Degrees of line production on metal-forming operations.

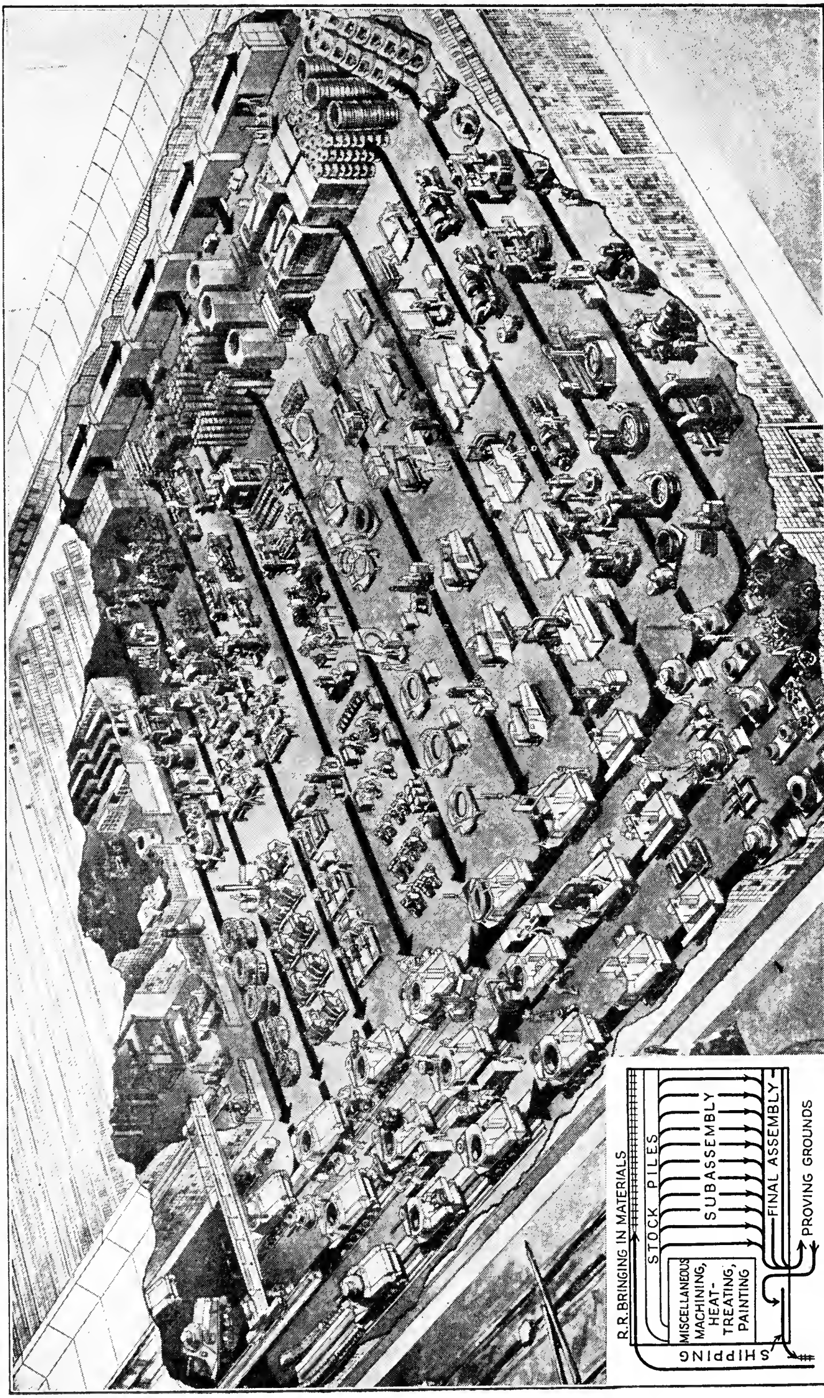



FIG. 5.—Flow through an entire plant is shown in this hypothetical tank arsenal where there is line assembly, line subassembly, and—top center and lower right—line fabrication. (*Courtesy of "Life." Copyright by Time Inc.*, 1942.)

*Line assembly with line fabrication* can be illustrated by the tank arsenal, shown in Fig. 5, where parts pass through their sequence of machining operations and into subassembly lines. In the manufacture of automobile frames, assembly and fabrication are performed on the same line.

Thus it is evident that line production is not limited to any one area. It can be employed within a two- or three-stage machine or in a series of production lines so closely coordinated that the entire plant assumes the form of one smoothly flowing unit.

Actually, it is often difficult to distinguish between functional layout, or job-lot production, and layout by product, or line production. Consider, for example, a series of cleaning operations on cast-aluminum cylinder heads. From the foundry these heads pass through several operations, including sprue cutting, inside blasting, outside blasting, snagging, seam grinding, and polishing. If these operations are arranged in sequence, with one man performing each operation and each piece passing from operator to operator, this would be considered line production. As soon as production increases to the extent that several operators are needed for each operation, then we may find four or five sprue cutters, three or four inside blasters, half a dozen outside blasters, two snaggers, and the like. While there is still flow through the several operations, there is actually a functional arrangement of work areas. There is, therefore, a rather fine distinction between the two layouts; and just where to draw the line is not easy to determine. It would be questionable to argue that as soon as two men are kept busy on each operation in any one line, the arrangement of equipment has become a functional layout. However, as soon as each operation requires several workers, the layout essentially does become one of flow through process areas. Actually, line production is seldom found alone, most companies employing a combination of both types of layout.

Nor can it be said that the distinction between line production and functional layout is that of the parts which are worked on; for many production lines have several different parts pass over them, and many machines in functional areas are, on the other hand, devoted exclusively to one product. This does not mean, however, that we cannot discuss the two types of production separately, for there are definite characteristics to be found in each.

## BEGINNINGS

There may have been early installations based on the principles of flow production in chemical plants, sugar and lumber mills, paper making, and other process industries. In manufacturing, the line-production concept apparently came from two sources. Certain small-arms companies had, as long as 50 years ago, developed interchangeable parts, though they had not rearranged their work areas. Of the two sources, one was in the small-arms ammunition industry with its dial-feed mechanism. This gradually led to the multiplunger bullet loading machine, not unlike the eyelet machine which developed around 1905.

The first extensive use of the progressive idea outside of one machine developed at the Ford Highland Park Plant.[1] In the early days of automobile assembly, each car was completely assembled in a fixed spot, and all the material was brought to it. Later, because of the difficulty of moving bulky stock to each fixture, the men progressed from car to car, each crew performing the same operations. Of course, there was confusion and extra handling of stock.

During a lull in business (about 1910), steel rails were placed on the floor in a part of the erection area. The workmen remained in one station but pushed the chassis along these rails after each group had finished its operations. A man at the end of the line had a stop watch, and at fixed intervals he blew a whistle, at which time each chassis was pushed to the next group of operators.

Later, a power drive was placed at the start of the line, and wooden spacers were introduced between each two chassis. This method worked rather well until one of the units jammed

[1] "How Mass Production Came into Being," *The Iron Age*, Vol. 123, No. 24, p. 1638.

and the line buckled to the extent that it pushed out the brickwork in the side of the building. To rectify this difficulty, the drive was transferred to the lower end of the line, and a chain designed which would be strong enough to drag the entire number of chassis along the rails. Soon thereafter, dollies were used to hold the chassis. Later, fixtures were attached to the chain, the chain itself being mounted on rolling supports.

During seasonal fluctuations in the automobile business, it was found that this type of line could accelerate much faster than the subassembly lines supplying it. Trouble developed particularly with the car bodies. When the chassis line increased, finished chassis would have to be stored, awaiting the arrival of bodies which could not be manufactured at such speed. This led to placing the body manufacture on a production line, which eliminated the delay.

With these initial methods of line production, the company converted department after department whenever a slack period in output permitted. Continuous washing, enamel-dip, and drying ovens were set up, and many other production lines were designed and installed.

There are indications that machining operations arranged for progressive manufacture preceded the assembly line. Many machines had previously been set up in sequence, and though the work was trucked or passed from operator to operator and the lines crudely balanced, the benefits of the production line for fabrication had been in part realized. An early attempt is found in the layout of the Ford cylinder-finishing department shown in Fig. 6.

Other industries have followed the automobile manufacturers. High-volume items, like radios, refrigerators, and electric motors, are typical of such products now made on the production-line basis.

## FUTURE SIGNIFICANCE

The importance of line production has been widely recognized. The large quantity of products needed in behalf of

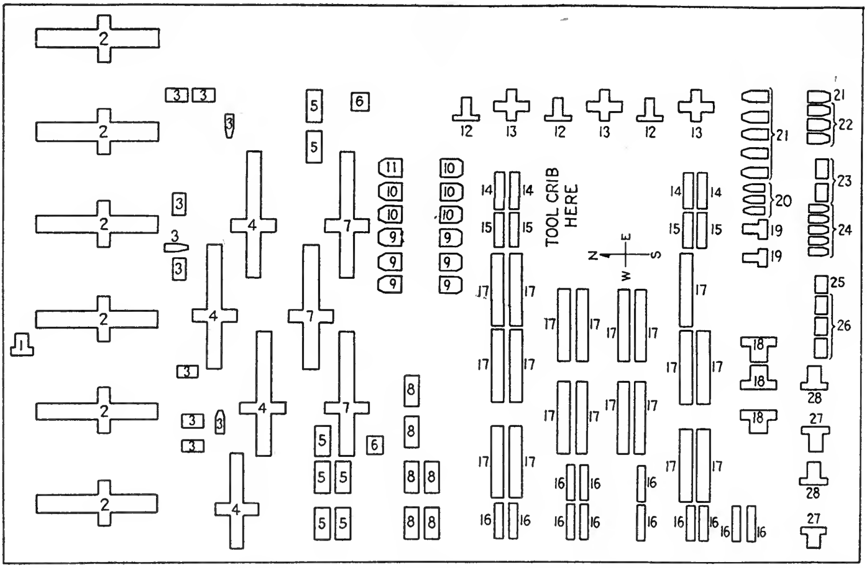



FIG. 6.—This layout of an automobile cylinder-finishing department shows the early attempts to obtain flow. All machines are devoted to one product. This was taken from the actual floor plan and is correct as to position, scale, and distance. The numbers correspond with the accompanying operations list. This picture appeared in the *Engineering Magazine* in June, 1914.

Cylinder-finishing Operations

| *Operation* | *Machine* | *No. of Machines* |
|---|---|---|
| 1. Spot | Ford Special | 1 |
| 2. Mill bottom | Ingersoll | 6 |
| 3. Drill 6 holes, ream 2 holes | Foote-Burt *and* | 7 |
| | Cin'ti-Bickford | 3 |
| 4. Mill top and sides | Ingersoll | 4 |
| 5. Rough bore | Foote-Burt | 7 |
| 6. Water test | Ford Special | 2 |
| 7. Mill ends | Ingersoll | 3 |
| 8. Finish ream | Foote-Burt | 6 |
| 9. Drill valve-stem and seat holes | Foote-Burt | 6 |
| 10. Drill, ream push-rod holes | Foote-Burt | 5 |
| 11. Ream valve-stem holes | Foote-Burt | 1 |
| 12. Mill door seats | Kearney and Trecker | 3 |
| 13. Drill 15 holes in 3 sides | Foote-Burt | 3 |
| 14. Ream crankshaft seats | Reed-Prentice | 4 |
| 15. Straddle mill crankshaft bearings | Hendey | 4 |
| 16. Finish transmission end | Reed-Prentice | 12 |
| 17. Bore camshaft bearings | Reed-Prentice | 19 |
| 18. Drill 45 holes in 4 sides | Foote-Burt | 3 |
| 19. Drill 14 anchor holes from 2 directions | Foote-Burt | 2 |
| 20. Spotface 15 holes | Barnes Drill | 3 |
| 21. Drill and counterbore 6 intake and exhaust ports | Foote-Burt | 6 |
| 22. Face time-gear end | Cin'ti-Bickford | 3 |
| 23. Drill and counterbore 3 core-plug seats | Foote-Burt | 2 |
| 24. Spotface mainbearing-bolt holes | Cin'ti-Bickford | 5 |
| 25. Face 2 camshaft retaining-screw bosses | Foote-Burt | 2 |
| 26. Mill water slots | Ford Special | 3 |
| 27. Tap 10 holes on 2 sides | Foote-Burt | 2 |
| 28. Tap 24 holes on 3 sides | Foote-Burt | 2 |

the national effort and the more or less standardized design of these products have for the first time allowed many manufacturers to establish production lines on an economical basis. On the other hand, for certain manufacturers, whose volume of production was temporarily reduced and for whom design changes were frequent, a much more flexible system was essential. These manufacturers found that they must recognize certain benefits inherent in the older type of layout where machines of a kind are grouped together.

On the whole, manufacture of war products definitely clarified the unique advantages to be gained from line production. It was the use of production lines that enabled this country to turn out such amazing quantities of matériel. In fact, the output of some plants newly set up for line production was so much greater than that thought possible by government arsenals and other job-lot manufacturers that certain proposed wartime expansion of plants and facilities was abandoned, and many plants cut back on their production because they were too far ahead of schedule.

We prophesy that many companies will attempt to capitalize upon this kind of manufacture. Cognizant of the advantages thus to be gained, they are likely to standardize their product designs and reduce cost through line production in order to obtain a larger sales volume.

Unusual demands for flexibility of products have, in a few cases, lessened the significance of line production. However, there is a strong feeling that, with the inevitable growth of emphasis upon lowered cost, the serialized line will find itself the dominant method of manufacture. Especially is this true where there is likely to be excess floor space and machine capacity, so that lines may be left intact and operated only intermittently.

# CHAPTER III

## ADVANTAGES AND LIMITATIONS

### UNDERLYING PRINCIPLES

Although line production consists of a specific layout of equipment and work areas, there is actually much more to this type of production than mere geographical arrangement. Once a line is under way, the complete sequence of operations on the product is normally performed simultaneously along the entire line. This continuous operation with progressive movement of the work involves certain fundamental characteristics.

**The Line as a Unit.**—In line production the complete sequence of operations rather than each work area or machine is considered as a single manufacturing unit. Such a line is designed to perform all the operations for one particular part or assembly, and all machines in the line are ordinarily devoted solely to this objective.

**Presence of Flow.**—As the various operations are performed simultaneously along the line, it is proper to consider the work going over this line as a flow of material. This flow is a dynamic concept which must be thought of in terms of a rate rather than a given amount. Thus it is common to speak of a number of pieces per day or per hour. Here is an entirely different viewpoint from that involved in job-lot manufacturing where work units are in terms of pieces or of lots. Rate involves the factor of time (pieces per period of time); and it is this time factor which is important throughout the entire consideration of line production, for each operation in a line is related to others by a common time factor.

**Thin Stream of Material.**—The concept of flow accords with the idea of a thin, swiftly flowing stream of material through the plant extending from the receiving department through fabrication, processing, and assembly to shipping. The material may actually move continuously as on a powered assembly line. This progression should be reasonably direct, with as few interruptions as possible. The importance of maintaining the flow so dominates this type of production that precautions have to be taken to ensure an adequate and uniform velocity.

For uniform flow the successive stages must handle equal volumes of material within equal periods of time. The timing of each operation must be such that it does not hold up other operations. Nor can it be faster than the other operations without the likelihood of waste. For perfect balance, every operation in the line should require the same time interval.

**Breakdown of Operations.**—If each operator in the line is to work for equal intervals on the material, and if the material is thus to progress uniformly toward completion, the total job must be ingeniously subdivided. This is usually accomplished by breaking it down into its simplest elements or combination of elements in order to effect equality in operations. Each operator thus performs a very minor portion of the work.

## ADVANTAGES

Line production should be recognized as essential for low-cost, high-volume, steady production. Statistics as to unusual savings in the cost of operation that have resulted from the installation of production lines are readily available elsewhere. Here its advantages may properly be arrayed, however, for comparison with the job-lot, or functional, method of manufacture. Difficulty immediately arises in determining which advantages result from the layout of machinery and work areas and which accompany the increase in quantity, the standardization of product, and the use of interchangeable parts. An attempt is made in this section to bring out the chief advantages that will result from the arrangement of equipment in a production line.

**Reduction in Handling.**—A large percentage of the cost of any product results from the nonproductive handling of work from operation to operation. This moving of material is greatly reduced in line production, for there is no back-hauling and the distances between operations are short. Many lines, in fact, are so arranged that one operator puts down the work where the next operator may pick it up. Moreover, line production lends itself easily to the benefits of mechanical transporting devices of all kinds from the simplest of chutes to elaborate fixtures built into a conveyor. In this way, the reduced handling of material benefits the operators themselves as well as the material handlers.

**Reduction of Inventory and Time in Process.**—Idle material in storage, though it may be considered as a protection, is no longer looked upon as an asset. Money invested in this material could be more profitably employed. More than this, there is always danger of loss through damage, spoilage, or obsolescence. In line production the inventory on hand is reduced to a minimum so that there is a much quicker turnover of capital. Material-in-process storage is almost eliminated in line production. The parts need not wait for other pieces in their lot before being moved. With immediate transportation there is practically no accumulation of material between operations. Since the rates of production are established, deliveries of incoming material can be scheduled in uniform quantities. Even the amount of finished stock may be lessened, for, with a regulated flow of output, promises to customers or dealers can be based on accurate calculations.

Naturally, with more direct handling and reduced inventories there is a faster flow of work through the plant. Not only does this result in an increased rate in the turnover of material, but the manufacturing time is actually shortened.

**Floor-space Saving.**—Along with reduced handling and less storage goes conservation in floor space, resulting from the lessened demand for aisles, storage areas, and conveyor space. Because the work moves directly between machines, there is no need for trucking to each work area. There is saving in floor area, therefore, for machines may be placed closer together than if equipment had to be arranged neatly along aisles.

**More Effective Use of Labor.**—In line production the breaking down of each part or assembly into a combination of simple elements allows greater job specialization; for the operator has to know only one or a few operations, and, performing these frequently, he soon becomes extremely efficient in his special task.

Moreover, the breakdown of operations permits a reduction in employee training. In conventional assembly with fixed location, each operator is trained to perform the complete sequence of operations, and there is considerable duplication of work and training. In line production the new operator is taught only a few operations so that he is able to begin work much more quickly. In this way line production makes use of unskilled and semiskilled workers at a saving in cost and a widening of the available labor supply.

**Ease of Production Control.**—Once the production line has been set up and the layout tested, it is a fairly simple job to control output. There is no question of stopping to route each lot, scheduling the work through each machine, or using alternate machines if the most suitable one is already in use. Checking material in process is reduced, for once the piece has started down the line, it cannot easily become misplaced. The problem is merely one of scheduling the line as a unit. This control over the line rather than over each operation lessens materially the work of the production-control group. The steady flow regulates production and practically guarantees the daily output that is planned. Along with this ease of production control goes the advantage of less clerical help.

**Tautness in the Operating Sequence.**—One of the psychological advantages of line production is the tendency to draw closely upon the work ahead. In most cases there will be but few parts between operations. Employees will make a constant effort to keep this material from building up ahead of them and to pass the work along promptly to the other workers on succeeding operations. This results in a steady pull from operations down the line which tends to increase production. Where there is a powered conveyor, the exact pace can automatically be set to hold the output to the desired rate.

**Ease of Supervision.**—The steady flow of work through the line automatically leads to the quick detection of delays. It also holds the operators at their work; on certain lines each worker must be on the job continuously. The foreman soon learns all the details of the various operations in his line. Moreover, he generally has functional experts to help him. Except for the problem of dealing with a less broadly qualified group of workers, supervision is easier.

**Reduced Interdepartment Problems.**—Whenever material is transferred from one department to another, there is an opportunity for argument over the condition of the work. In the line arrangement of equipment, a complete part or product is made on one line. The supervisor is responsible for all operations, and he need not rely on work coming to him from some workman over whom he has no control. This reduces the interdepartment rejects and the need for interdepartment inspection. Moreover, since supervision over all the machines in one line is delegated to one person, the responsibility for the work is squarely placed upon him. This layout by product makes a true executive of the foreman.

**Less Congestion in the Work Area.**—When workers have to move from one work area to another and parts have to be carried from one storage area to several assembly locations, there is opportunity for confusion. Likewise, when material is trucked about the shop to get to the next operation, order is difficult to attain. In line production, material is brought directly to the operators who may have to move very little to perform their work. Stock which is to be assembled is always located in the same place. Thus, in the line arrangement of work areas, there is less congestion of materials, employees, and portable equipment.

**Enforcement of Operation Study.**—When a production line is installed, it works as a unit. Recognition of this necessity causes a critical examination of every phase of the job. This demand for thorough analysis of all details leads to many improvements in operations which might otherwise never have been noticed. Thus efficient performance of the work follows.

## LIMITATIONS

The chief limitation of line production is that it demands a reasonably large quantity of a fairly standardized product. In factories where a large variety of products is manufactured in relatively small amounts, the cost of constant re-layout and changeover of equipment prohibits the use of line production. In these cases, it has been found more economical to arrange machinery according to the function to be performed, for this allows greater ease in conversion from one product to another. The saving to be made in the cost of any one job is not sufficient to justify the cost of rearranging previously placed equipment. Generally speaking, the job-lot plant is strong in the areas where line production is weak.

Obviously, no line can be set up where there is only one operation to be performed. Likewise, there can be no line where it is possible to run off sufficient parts in a few hours to satisfy production requirements for several months, as is common in the case of automatic-screw-machine operation, tube bending, and much stamping work. In certain cases where speed of getting into production is important, the program cannot wait until a production line can be set up. However, for further examination of the limitations of line production, a discussion of some attempts that have proved unsuccessful will serve.

*Examples.*—One manufacturer of electrical devices installed an expensive system of conveyors in his plant in the belief that this would give him line production. He soon found that the conveyors took up much floor space and led to inflexibility. They were, therefore, abandoned in favor of trucking the material, and the manufacturer was convinced that line production would not work in his plant. Actually, since no attempt was made to arrange the equipment in a truly progressive sequence, he could not expect to secure the benefits of line production. Conveyors alone do not mean line production.

In making small parts for aircraft, one company attempted several line installations but found that there was no standardization of these parts within the industry. Every newly designed plane called for slightly different part dimensions. This constant variation in the product meant that the company could not adapt its tooling to such variation. Since the machinery needed constant readjustment, the company decided to give up its idea of line production.

Another instance occurred in the production of aircraft parts by an automobile company. Engineering changes occurred with such frequency that the company was continually required to change the operations and alter their sequence. This meant constant rearrangement of the line. Such design changes are particularly difficult in line production; for, even though there is less material in process and therefore the change can perhaps be made faster, it will be pure accident if, when undertaking the new design, the manufacturer has the most suitable equipment in kind and amount in his existing line.

Flexibility of layout is extremely important in line production. One concern making special insulating porcelain for electrical and radio work set up a series of several parallel lines. The machinery was fixed to the floor and expensive dust-collecting systems installed with ducts to each machine. It was found, however, that the various pieces of work which were to pass over the lines were not always well adapted to the established sequence of equipment. Could the machinery have been moved more readily, the lines could have been changed over for each part which deviated from the normal order of operations.

A similar situation arose in a leatherworking plant where production lines were set up, but overhead line shafting was installed to drive the machinery. When it became necessary to rearrange the plant, machinery could not be moved easily. Had the machines been equipped with individual motor drives, the line would have been more versatile.

A primary advantage of job-lot layout is its increased utilization of machinery where the volume of output is low. In line production the capacities of the various machines are seldom the same. This often results in idle facilities. Many companies have abandoned line production because it tied up expensive or critical equipment with only a light machine load, yet the equipment could not be used on other work. One company assembling fuse components partly discontinued its lines because its inability to break down operations with adequate balance resulted in idle equipment and operators.

Delays in the flow of material through the line may cause subsequent operators to become idle. Whether the delay is caused by shortages or rejection of material, breakdown of machinery, absence of operator, or some other irregularity, the later operations will be held up if the delay is not quickly rectified. Unforeseen difficulties of this kind so affected one factory that shipments were delayed and the morale of employees materially lowered.

One manufacturer making gun parts organized his layout for a certain quantity of parts per month. Before the machinery was even installed, the production schedule was doubled. Production began in a limited way, and later the line was rearranged so that the extra machinery could handle the increase in schedule. Still another schedule change came through, and the line had to be entirely laid out a third time. The line was not a failure, but difficulty and added cost were encountered as a result of varying production requirements.

The case of a pressed-metal company is perhaps more unusual. The concern set up a rather ingenious assembly line to turn out the required number of pieces per day. But the sole customer of the product discontinued purchasing the item after three months. The manufacturer had assumed that the job would run for the entire year and the expense of tooling and layout of the line was charged against the entire yearly production. The result was that the short run did not cover the cost of the line installation.

It is not possible to buy production lines by the foot. One industrialist, impressed with the advantages of line production, rearranged his final assembly area and assumed that this would give him the benefits of serialized production. He overlooked such factors as interchangeable parts, balanced time for the various operations, and adequate scheduling of parts to the point of usage.

The lack of appreciation of the necessary preliminary work caused such confusion that the line was considered impractical.

Frequently, operators are opposed to working on lines, particularly if they are accustomed to a functional layout and have never seen a flow-production setup. In a company making precision instruments, and again in a shoe factory, employees were radically opposed to line production. In the first instance the line was discontinued to keep harmony in the plant, while in the latter a modification was worked out. Before changeover to line production it is wise to acquaint the workmen as well as the supervisors and management with the advantages of this type of manufacture. Tradition and a habitual way of doing things are difficult to overcome.

One concern had to discontinue its line production when the one man who understood its functioning left the company. In another instance lines were found of no advantage because the product being manufactured had to be moved into a centralized government-inspection area after each operation. Other difficulties have arisen when management and workers were unwilling to operate a line set up by an outside consultant; when lack of quality standards resulted in less interchangeability of parts; when there was a desire to keep certain machines grouped together merely because they were new.

These unhappy examples show that line production does not invariably lead to effective manufacturing.

## PREREQUISITES

From the above limitations we can deduce certain prerequisites of line production. Probably the most important factor in considering the desirability of a production line is the *quantity* or *volume of production*. And quantity is not always easy to specify. Two hundred units a day is normally a very small output in automobile manufacturing; yet when such a producer is building tanks, he finds that production of ten a day warrants doing most of the work on lines. It is doubtful if any formula can be set up which will hold in all cases, for the proper quantity varies too much with different products.

If the quantity is large enough to keep busy every machine over which the work passes then a line is surely worth while. Lesser output requirements may, however, justify line production. In comparing the machine loading in the line with that of a job-lot layout, the times required for handling, loading and unloading, teardown, setup, and waiting must be considered.

Quantity is normally determined by the market or demand for the product. The sales department must supply figures on the expected yearly volume, with variations for each month, and perhaps market-study figures of the next several years, before the manufacturing division should begin planning its lines. The *length of time the job will last* should be at least enough to cover the expense of tooling up and arranging the equipment; the interval may, however, be as short as a few days where the equipment is particularly flexible.

The time relationship to quantity will be established in two ways. One of these employs the number of working hours (days of the week and hours per shift). The quantity called for per week divided by the number of operating days or hours per week gives the *daily* or *hourly rate of production*. It is this rate-of-production figure that must be known by the manufacturer in order to set up his production line.

Again, the *time required for each operation* will be materially affected by the nature of the process, the size, weight, and shape of the part, the method of handling the work, the quality required, the space available, and like considerations.

In the case of assembly work, the problem of maintaining a volume that will keep machines properly loaded is not so great. It is more a matter of keeping operators busy. The quantity needed for assembly on a line basis is that which will allow each operator to perform his portion of the operations repetitively for a reasonable period of time. As soon as the quantity to be assembled is large enough to keep two operators busy, it will pay to divide the operations, provided the elements of the job can be apportioned fairly evenly.

In addition to an adequate quantity lasting for a reasonable period of time, there must be a *standardization of product;* that is, the parts and products to be made must be standardized to the extent that they will, on the whole, remain the same or similar as long as the line is in operation. Changes in design can be accommodated, but usually it is essential to have the product unvaried long enough to permit an economical run.

In this same connection, dimensions and material specifications on all parts must be such that the *parts are operatively identical.* Any variation beyond permitted tolerances will disturb the flow of work and increase the cost of production. When parts arrive for assembly, if they do not fit or have to be fitted and filed, the time for the operation cannot be predetermined, and a balance of operations cannot be realized. Interchangeability is part and parcel of line production.

In the operation of any production line it is important to have a well-organized planning department. Since uniform flow on the line is essential, every precaution must be taken to *assure a continuous supply of material.* If for some reason shortages of material develop, then the whole line remains idle. The scheduling of incoming supplies and of the various units through fabrication and subassembly must be maintained and expedited so that they will come to their point of assembly at the proper instant.

All these factors may be considered as prerequisites to line production. There are others also important, such as individual drives on machines, predetermined standard times for various operations, and an alert maintenance and toolroom group. These are resources which will be considered in later chapters.

## COST ASPECTS

It is profit, savings, or return on investment which, in the last analysis, normally determines whether a line can be justified and what kind of line will be set up. The installation of any line should always be preceded by a study of the costs involved in establishing the line and the savings resulting therefrom.

Typically, the production line is only one of several possible methods of accomplishing a desired production result. It should be made to prove itself from the cost viewpoint as compared with other possible alternatives. A sound method is to compare costs based upon *equal total production.* Often a production line is under consideration because of the need for increased production over present output. Again, the proposition may involve no change in total production. Whatever the circumstances, it is necessary to build up costs for each alternative method based upon identical total volume; otherwise, no true cost comparison is possible.

Only cash-out-of-pocket costs need to be considered. Let us suppose that plans have been prepared for a production line designed to supplant an existing method of manufacture. No increase in total volume is contemplated, the urge to change manufacturing methods having arisen from the belief that the present method is wasteful of labor and materials. To manufacture the desired quantity using present equipment and methods may require no cash outlay for machinery but will cost a certain total amount for labor, materials, supervision, planning, etc. Establishing the production line will require cash outlays for purchase or rearrangement of equipment, to which will be added a budget for labor, material, supervision, planning, and other items of expenditure computed in terms of the production plan to be followed if the proposed line is put into operation.

Computations made in this manner develop the total cash costs of each alternative method of manufacturing the desired production quantity and result in direct comparisons of the various alternatives. The use of cash costs places the burden on the proposed method to prove that it is indeed more efficient. This is as it should be. Under conditions where a present method is adequate to handle the desired production volume, a new method, to be profitable, must be so economical of labor and materials that it more than compensates for the costs of installation and for the losses arising from scrapping the old equipment. The cost approach described above forces the proposed method to provide for the loss of scrapping present equipment in cases where newly purchased equipment wholly replaces existing facilities. This is true because the full cost of new equipment is included in the totals for the proposed method, whereas cash equipment costs for the present method will be listed at zero or at scrap value.

The cash-outlay approach has equal validity under conditions where the production line is proposed to handle a total volume in excess of that which can be produced under existing methods with present equipment. Total costs of the proposed production line for the desired volume would be prepared in the manner described. In computation of costs for the present method it would be necessary to include the cash outlays essential for such added equipment, space, etc., as would be needed, and necessary to project present labor and material costs into the higher volume range. Of course, it is under such conditions that production-line proposals most easily prove their economy, but it should be emphasized again that a true cost comparison cannot be made except as alternative methods for doing the *same total task* are considered.

The cost comparison is useful and important but is, after all, only one of the factors to be considered by management in deciding upon a manufacturing method. A number of such factors have been mentioned in this chapter. Another which merits discussion is the element of financial risk, which often appears to dominate the final decision in the installation of a production line. A careful cost study should help in the appraisal of this problem. If the cost comparison shows substantial savings to be made by the proposed installation, the financial problem should solve itself; if the savings are real, there will be no better way to invest the company's owned or borrowed funds.

In a decision of this kind, financial uncertainty can only be the reflection of uncertainty as to the production and cost factors involved. If a study of these factors shows only a slight margin of superiority for the proposed line, and if the intangible risks loom large, then the proposal probably is a poor financial risk.

If, on the other hand, the market is stable and certain, if the cost and production studies show a substantial saving for the production-line method, and if intangible risks have been analyzed and appraised, then it should be possible to meet the initial financing involved. If this cannot be accepted as a principle, then a company is not justified in going to the trouble and expense of even a preliminary plan for line production. For if it must be assumed that a proposed line cannot be financed, there is no sound basis for making a cost comparison between alternatives, one of which will involve substantial outlays of cash.

Probably the most difficult factors to appraise in a cost comparison are such items as handling costs, maintenance, floor space, supervision requirements, and production control, along with relative flexibility, safety, working conditions, and employee morale. The difficulties involved in appraising these items fade into relative insignificance when compared with the problems of measuring the intangible risks involved in future behavior of the market, the rate of technological advance, changes in design, etc.

Every company faces these problems constantly and is consciously or unconsciously making decisions concerning them. Often failure to be aware of the problems results in decisions as irrevocable as though they had been carefully appraised and constructive action taken.

The experienced manager, with his intimate knowledge of the problems of his own company, is in a position to evaluate properly the intangible risks and to place them in perspective in consideration of each production method alternative. It will be our purpose to supply a broad foundation in the principles, operating problems, and techniques of line production so that he may make such specific applications to his own production problems as may be warranted.

## EXECUTIVE READING

"Straight-line Production," Alexander Hamilton Institute, New York, 1932. A booklet in which C. D. Hart and J. R. Bangs discuss layout by product and layout by process.

"Going 'Straight-line'?" *Factory Management and Maintenance,* Vol. 97, No. 1, p. 69. Hugh L. Thompson points out the problems that are usually encountered in establishing the line-production method.

"Flow-work," International Management Institute, 1933. A small book containing simple illustrations.

"Improving Manufacturing Facilities," Bureau of Commercial and Industrial Affairs of the Boston Chamber of Commerce, 1922. Chapter 3, "Progressive Manufacture," discusses the fundamentals of line production.

"Only a 30-man Plant—but It's Mass Production," *Factory Management and Maintenance,* Vol. 95, No. 12, p. 76. T. B. Funk, president of Yard-man, Inc., of Jackson, Mich., discusses the line-production method in the manufacture of lawn mowers.

"Continuous or Flow Production," *Mechanical Handling,* Vol. xxvii, No. 12, p. 283. A brief article in a British trade journal which stresses the importance of determining the rate of production flow.

"Erfahrungen mit Fliessarbeit" ("*Practical Cases of Continuous Processing*"), Vols. I and II, edited by the Ausschuss für Fliessarbeit beim A.W.F., published by Beuth-Verlag G.m.b.H., Berlin, 1928 and 1931.

# PART II

# ESTABLISHING THE LINE

## CHAPTER IV

## METHODS AND EQUIPMENT

Part II of this book deals with the less spectacular phases of line production which lie back of the fabrication of parts and the final assembly line. The product analysis, process engineering, tool designing, balancing of operations, estimating of man power, plant-layout work, and installing of equipment—these preliminary activities are just as much a part of line production as are the actual assembling and fabricating of parts. Each step in establishing the line must be precisely worked out or disturbances will interrupt the flow of production. If the line is set up correctly, its operation becomes relatively routine.

This preliminary phase applies to the setting up of any line, whether it be a simple, short line, the changeover of a single department for a new model, or the conversion of an entire plant. The more radical the change in the design or manufacture of the existing product, the greater will be the work involved, and the more time-consuming will be the procedure. It took the first wartime tank producer a year to tool up and build his first M-3 pilot job. Preparation included a visit to the government arsenal, the study of blueprints and parts, the making of a wooden mock-up model to aid in visualization, the layout of assembly operations, the location of subassembly and fabricating lines, and the selection of the necessary machines and their arrangement. In the case of the M-4 tank it required another company just 47 days to turn out its first tank. This was largely because the initial organization had made available to the second company all the information which it had accumulated in the tooling and organizing of its production lines.

The importance of setting up the line has been expressed by Kettering, who says, "We don't manufacture these automobiles—that is, not in the usual sense. It is more like the publishing business." To carry the analogy further, a great amount of time must be spent writing the copy, setting the type, making the engravings, correcting the proof, buying the paper, and getting it cut to size. All this having been done beforehand, once the presses are rolling, it is nearly as easy to produce a million as to run off a few thousand. If the line is to "publish" finished units at a desired rate, all the problems that precede the actual producing of goods must be resolved. A smooth-running line only proves that this preliminary work has been performed satisfactorily. Unless this principle is recognized as important, a company may find itself with an inadequate technical staff when the time comes to work out such details.

Having noted its importance, let us see what this preliminary work includes. With the product correctly designed, it is necessary to break down the final unit into its various subassemblies and parts. Detailed drawings of the various parts should be made and material specifications drawn up. Each part should be studied to determine exactly how, in what sequence, and on what equipment each of the various operations will be performed. Cost estimates should be made on which to base decisions as to whether to make or purchase. Operation times for the parts to be manufactured and the number of machines and operators necessary should be calculated. All new tools should be designed and made up or purchased. The layout of the productive areas and arrangement of machinery and equipment should be planned. Vendors should be selected and sample materials and parts obtained. Finally, when the equipment and tools are installed, initial sample parts should be tried out over the line to locate and remove all difficulties. Only after all this preliminary work has been completed is the line turned over to the operating group, ready for production.

## PRODUCTION ENGINEERING

The work of setting up a production line is shown in Fig. 7. While no two companies follow exactly the same procedure,

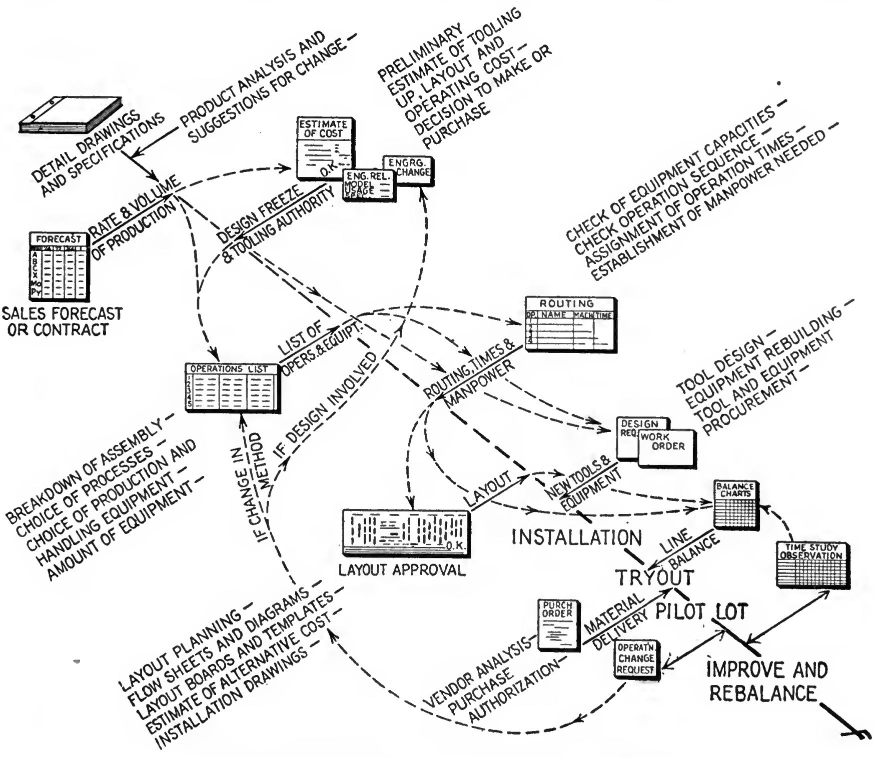



FIG. 7.—Production engineering for a production line.

the functions that generally have to be performed are indicated here. In some plants this is the work of several different departments. In others, a single industrial engineer may have charge of the entire job. At times an outside industrial consultant or manufacturer of equipment may do this work. An attempt is here made to show the nature of the work to be performed rather than to specify the duties of each of the many different kinds of engineers who may be involved. This work will be referred to as *production engineering*, a term which in its broad sense includes product analysis, processing or methods, materials handling, plant layout, line balance, and installation.

Production engineering for line production differs from that in the job-lot plant in two important ways. In the first place, for line production a contract or forecast of orders must be determined before a line can be set up; whereas, in job-lot plants, equipment is already in place before the forecast is made. Requests for estimates from potential customers may allow the job-order plant to determine its operations, routing, and producing times before the receipt of actual sales orders, but the layout will not be changed with each new forecast, product, or manufacturing operation as is the case in line production. Though this limits production efficiency in the job-order plant, it does make for greater flexibility.

This is perhaps the reason for the second difference: changes in product or improvements in manufacturing methods will result in more frequent readjustment of the line. Where equipment is devoted to but one product, improvements can be made without consideration of any other product; but where the line acts as a unit, a change at one point may involve rearrangement of all subsequent operations.

## DESIGN FOR PRODUCTION

All manufacture is built around the design of the product; if we are to make a form utility, we must know what the form will be. We do not intend to touch upon the ways of conducting experimental work and the technical details of product engineering and design,[1] but we should be negligent if we did not point out that there are two aspects to design. *Functional design* is the result of developing and improvising a part or assembly which will perform a specific purpose. Its only requirement is to function satisfactorily in accomplishing the purpose for which it is intended. *Production design* consists of a critical study of the details of functional design with a view

[1] While this field of activity is of great importance to line production, it is essentially a matter of design rather than of production.

to making changes which will simplify manufacture without affecting function. The complete detailing of all manufacturing information is often considered a part of production design. While functional design assumes the meeting of performance requirements, it is production design that gives economy of manufacture. In all too many cases there is a tendency on the part of the initial designer to overlook the limitations caused by the production processes, the equipment available, and the costs of operation. Actually, the design engineers work between the sales and manufacturing divisions, reconciling the requirements of both.

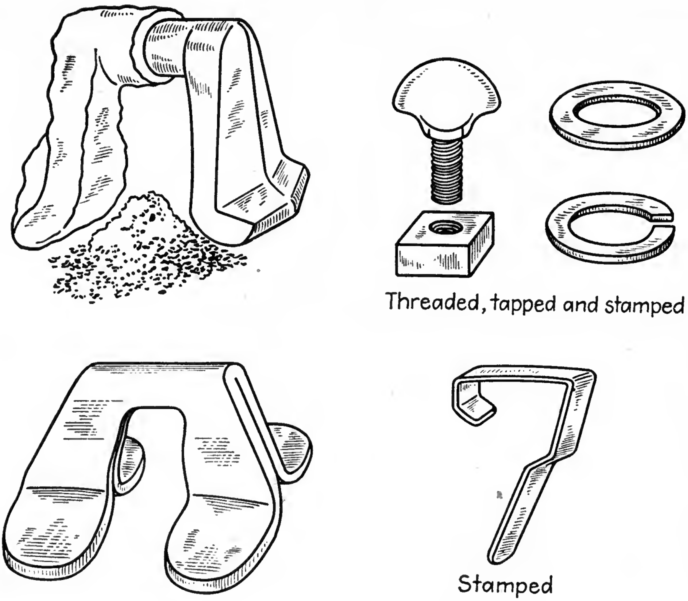
**Changes in Design.**—Changes in design which can aid production generally involve the shape of the product and its dimensions, although changes in material, treatment, and finish, and all other specifications are equally important factors in making a suitable production design.

In examining any new job, production-minded engineers aim to answer two questions:

Can the parts be made and assembled with present prints and specifications?
Can they be changed in order to be made and assembled more easily?

It is surprising how many products are initially designed which cannot be made easily or which require special equipment. Sometimes tools cannot reach the desired point of operation, or parts can be assembled only after extensive fitting and adjusting. For interchangeability, which is so important in line production, drawings and specifications must be carefully surveyed and altered to permit easy and inexpensive fabrication and assembly.

One example of a change in styling occurred in the manufacture of a metal door handle. It was originally designed with deep indentations. These grooves had to be shallowed out and rounded off in order that automatic polishers might be used. Otherwise, hand-polishing operations would have had to be performed at a much greater cost. Figures 8 and 9




*a* *b*

FIG. 8.—*a*. The change in design of this lug so that it could be stamped instead of machined saved 8,000 machine-tool hr. and 17,000 lb. of steel on a lot of 100,000 pieces. *b*. The changed design allowed this clip to be made 150 times faster. The weight is about 1/8.

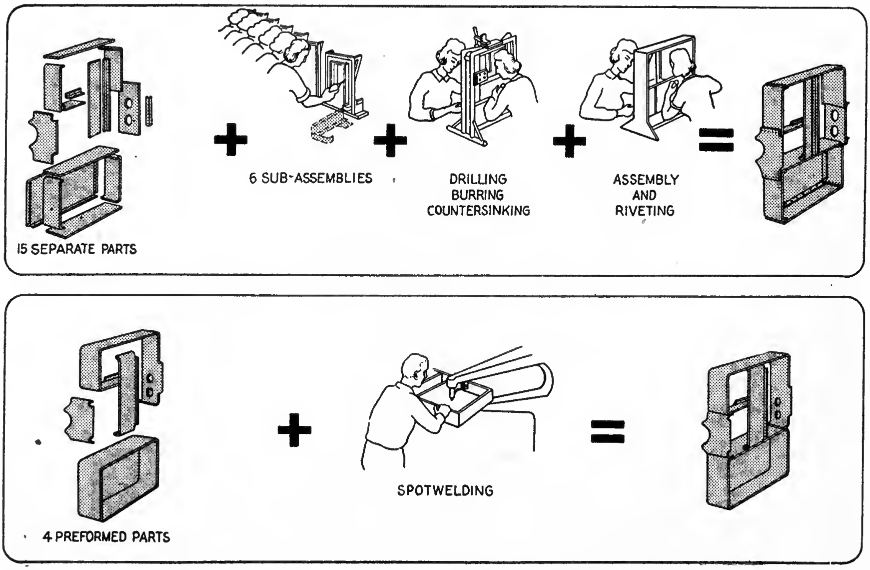



FIG. 9.—Redesign for ease of assembly replaced 15 separate parts by 4. (*Courtesy of Lockheed Aircraft Corporation and Automotive and Aviation Industries.*)

show other examples of changes that have resulted in better methods of production.

Where a manufacturer accepts a product and its design from an outside contractor, it may be difficult to have changes approved. Yet, if he is planning to set up a line or if by other means he is planning a large output of the product, redesign in the interests of production may prove well worth while.

**Facilitating Production Design.**—Within any one company the experimental work and functional design may proceed without consideration for manufacture. As soon as decisions are reached as to what parts will make up the finished unit, representatives of the manufacturing division are consulted. Many difficulties can be eliminated here. Changes at this time can be made easily and with great saving. As the design develops, more and more of the production point of view can be incorporated so that when the detail drawings and specifications are finished, a complete restudy for production design will not be necessary.

Close relationship between the designing and manufacturing groups may be obtained in as many of the following ways as seem desirable:

*A separate production design or engineering analysis group* may be organized to readapt all blueprints and specifications for ease of manufacture. Although expensive, this procedure is of particular value on work submitted by outside users.

*Representatives of the production engineering group* may work full time or intermittently with the designers. A less specific though even better device is for designers to go into the plant and learn at first hand the limitations of production.

*Project or product engineers* may be assigned to coordinate the production engineering work on certain products from the predesign stage through to the operation of the line.

*Advance designs* may be issued to the production engineers for study and approval. This arrangement allows release of official designs at a later date, which is particularly advantageous in a highly competitive, seasonal model.

*Sample laboratories and test or pilot lines* for thorough study by both the design and manufacturing groups may be established.

**Releasing the Design.**—The fixing, or "freezing," of the design follows any final adjustments for ease of production. Detail drawings and specifications are approved by the chief engineer, identification on advance-design prints is removed, and records of part numbers are checked in preparation for the making up of parts lists and bills of materials. An engineering release or design-information order is then issued to

ENGINEERING RELEASE

PROJECT Gun Carriage DATE 5-28-42 PART NO. BCU12PC
SUPERSEDES --- INSPECTION CODE 4A REL. NO. 3118

| MODEL OR GROUP NO. | NO. REQ'D PER ASS'Y |
|---|---|
| B-1 | 1 |
| B-2 | 1 |
| D | 1 |
| | |
| | |

NEXT ASS'Y. DRWG.
176647

PART NAME SCREW HEADLESS
GROUP NAME GREASE INJECTOR
DRAWING DATE --- REVISION DATE --- INCLUDING CHANGE
MATERIAL SPEC. STEEL
STOCK SIZE
ROUGH WEIGHT EST. WEIGHT ACTUAL WEIGHT
GOV'T. SPEC.
VENDOR SPEC.
SERVICE REQUIREMENTS
JOB NO. SECTION NO.
LINE UP

PURCH. IN 176647 DELIVER TO PLANT 2

REMARKS: HDLSS. CONE PT. .164 (=8) 36 NF-3 X 5/32

LETTER NO. ORDNANCE LET. 94 APPROVED BY MERRILL
EFFECTIVE #1 JOB DRAWING SIZE 9 x 12

FIG. 10.—Engineering release.

accompany prints and specifications. An example of this order may be seen in Fig. 10. This acts as an official release of the design to manufacturing and is notification that the design has been fixed. It sometimes also serves as an authorization to those responsible for setting up the line to proceed, although an approved estimate of cost or authorization of funds is commonly required. An effective date for initial production may be specified on the release, and it may be issued only after production or purchase authorizations are approved, but a design or engineering release alone should not act as authorization to begin producing. The release does not mean that future improvements in design cannot be adopted. They

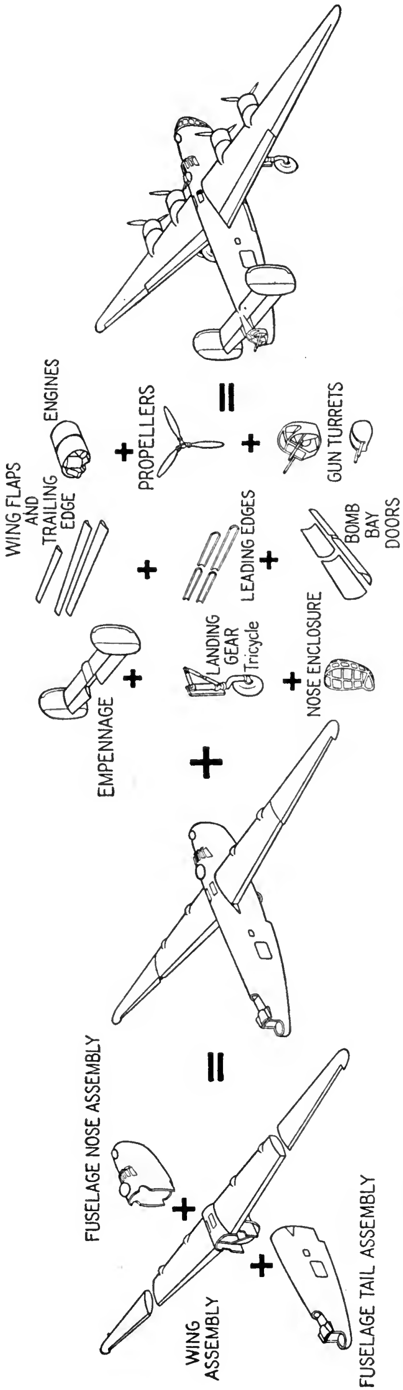



FIG. 11.—This sketch illustrates the breakdown of a complete aircraft into its subassembly parts. Plans will be made to assemble these components to the major unit at various stations along the line, as is shown in Fig. 12. (*Courtesy of Consolidated Vultee Aircraft Corporation.*)

should be authorized whenever approval as to functioning and performance is given by the design group.

## PROCESS ENGINEERING

Process engineering consists of determining the manufacturing operations and facilities that will be required for any

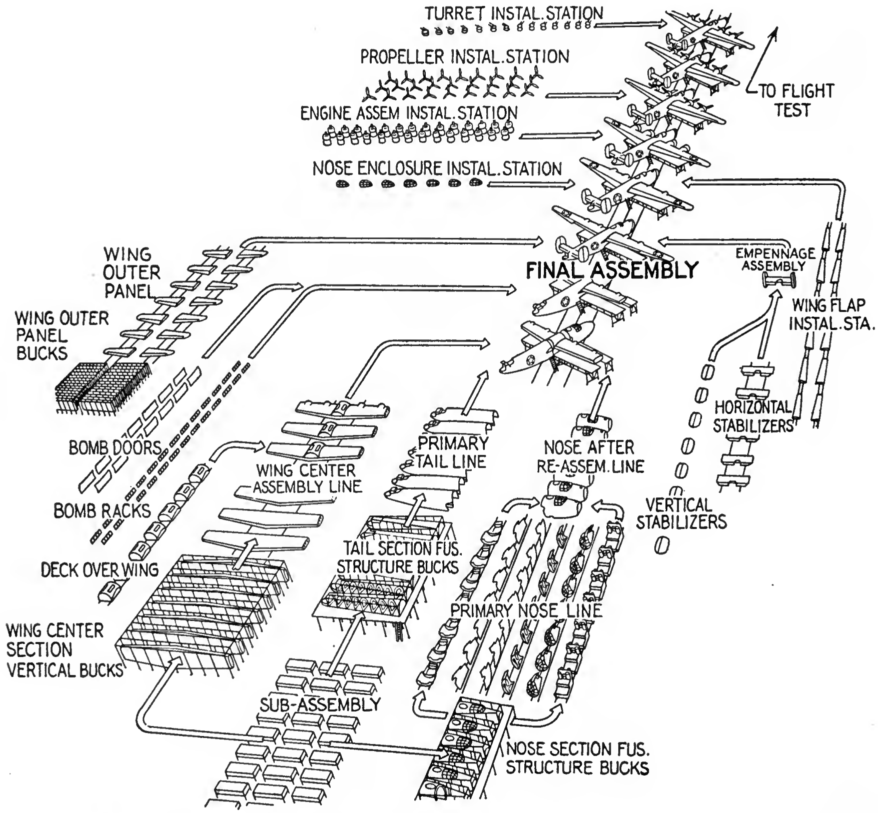



FIG. 12.—The concept of a plane does not begin with the parts; every plane is conceived and designed as a whole. Only then do the production engineers step in and determine how it can be carved into pieces, to permit volume production. This schematic diagram shows the major pieces of the plane shown in Fig. 11, and how they are put together. Good design breakdown results here in simple operations and fast assembly with each part "mating" at its proper assembly station. The diagram should not be mistaken for a plant layout. (*Courtesy of Consolidated Vultee Aircraft Corporation.*)

product. It involves the breakdown of the final assembly into various subassemblies and parts, the determination of the methods and equipment to be used, and the sequence in which operations are to take place. This is illustrated on a large scale in Figs. 11 and 12.

For any mass-production job this aspect of production engineering is of fundamental importance. Quantity production can support considerable cost of specialized tooling because of the resultant saving on the large number of pieces made. In plans for a production line, therefore, the experience and resourcefulness of those who process the product will certainly be reflected in operating costs. Real progress in the manufacture of most products has come through technological advance in the methods of manufacture as well as in the design of the product itself.

Before the work of processing actually begins, it is advisable to bring together the heads of all the production-engineering activities concerned with establishing the line. As these engineers are mutually responsible for the several activities of arranging the line, it can be set up properly only if they collaborate closely with one another. By joint initial study everyone will know how the work is to be handled, and many troubles will be foreseen and offset. Moreover, the work of each group is so dependent on that of the others that the offices of the process engineers, plant layout group, and time-study analysts are desirably located in close proximity to each other.

**Division into Components.**—Figure 13 diagrams a procedure for line development. Where breakdown of the product into its subassemblies and component parts has not been decided upon before the release of the design, this will be the first step in processing. Such a step has two objectives:

To make assembly and subassembly of parts as easy as possible;

To keep all work off final assembly lines that can be done conveniently in subassembly or fabrication.

With entirely new products, the breakdown and future processing may be visualized by such aids as wooden mock-ups, working models, or perspective drawings. These show the

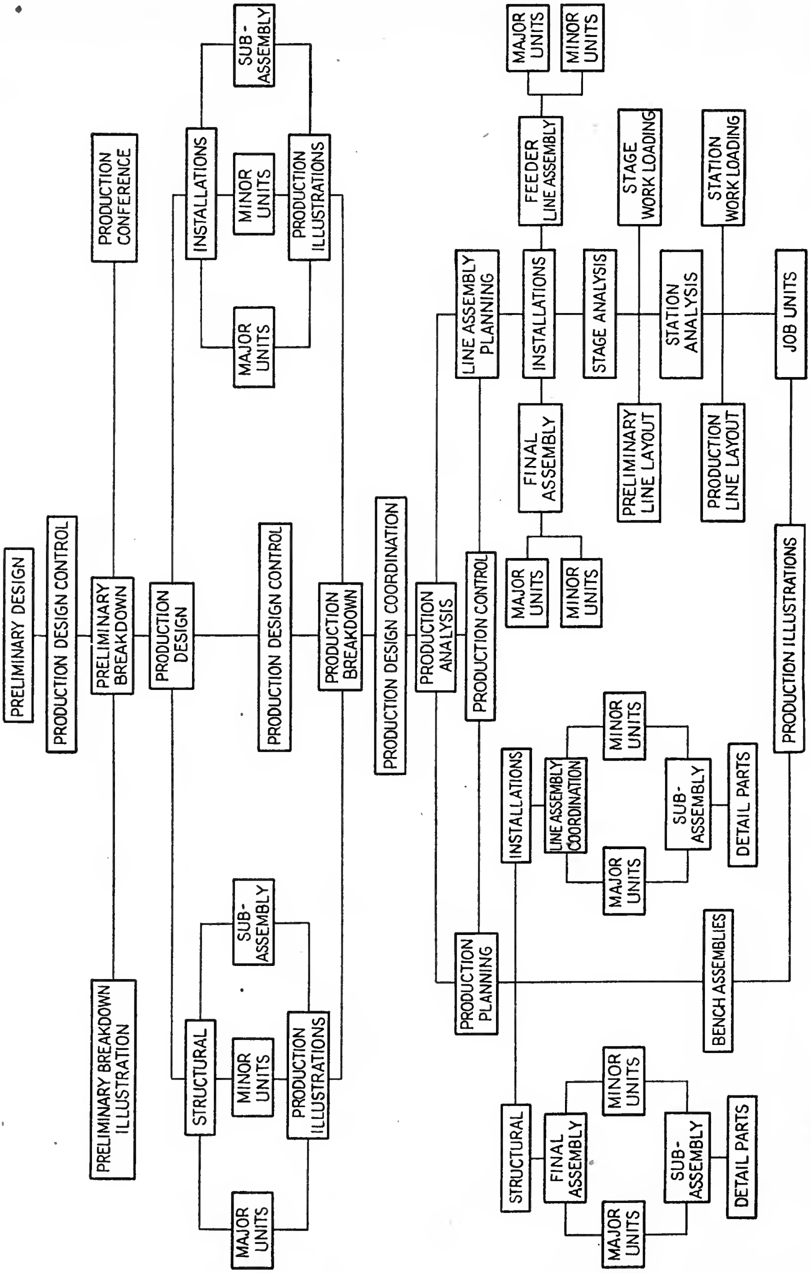



FIG. 13.—Procedure for developing assembly lines as outlined for an aircraft company. (*Courtesy of Aviation.*)

parts and how they go together and also indicate the room available within the assembly for accessibility of tools, hands, or workers themselves. With a reduced number of operations on the major lines, fewer bulky assembly units and expensive assembly fixtures, and less floor space will be required. Figure 14 shows how important it is to do as much work as possible on subassembly lines.

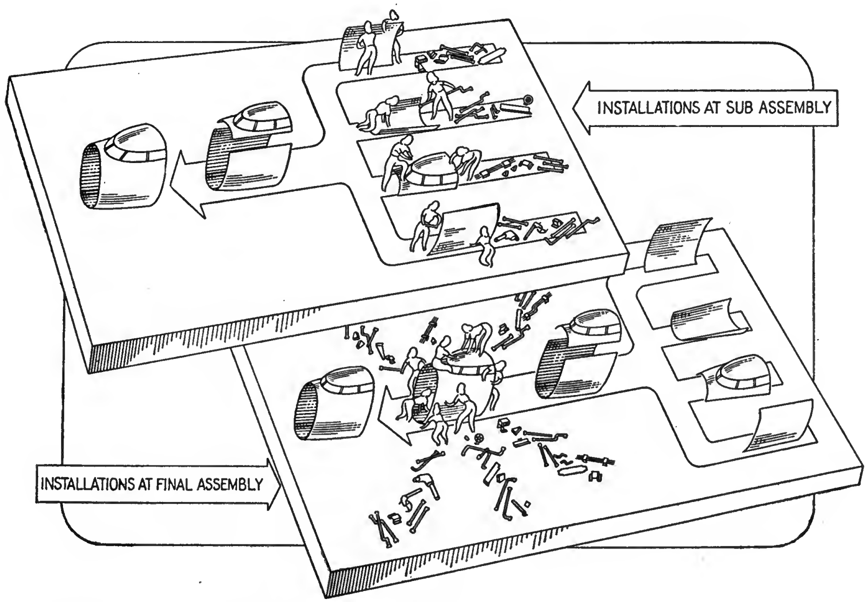



FIG. 14.—Two methods of making installations. The lower sketch shows the difficulty of performing the same operations after the subassemblies have been put together. (*Courtesy of Lockheed Aircraft Corporation and Automotive and Aviation Industries.*)

**Choice of Processes.**—There are usually several ways to make any part or assembly. If a production design has been properly worked out and an analysis made of the necessary operations, the process engineer already has in mind the methods that will be used. More important than when he makes these decisions as to method is the fact that there is opportunity for choice. Process engineering for the job-lot plant has greater limitations, for the processes already installed in the plant must be used inasmuch as the small job will not pay for a new method.

As an example of this choice, note the differences in the manufacture of a certain main drive sprocket. This item was initially made by flame cutting from steel plate. Scrap cost was high, and a change was made to forging. Die life being

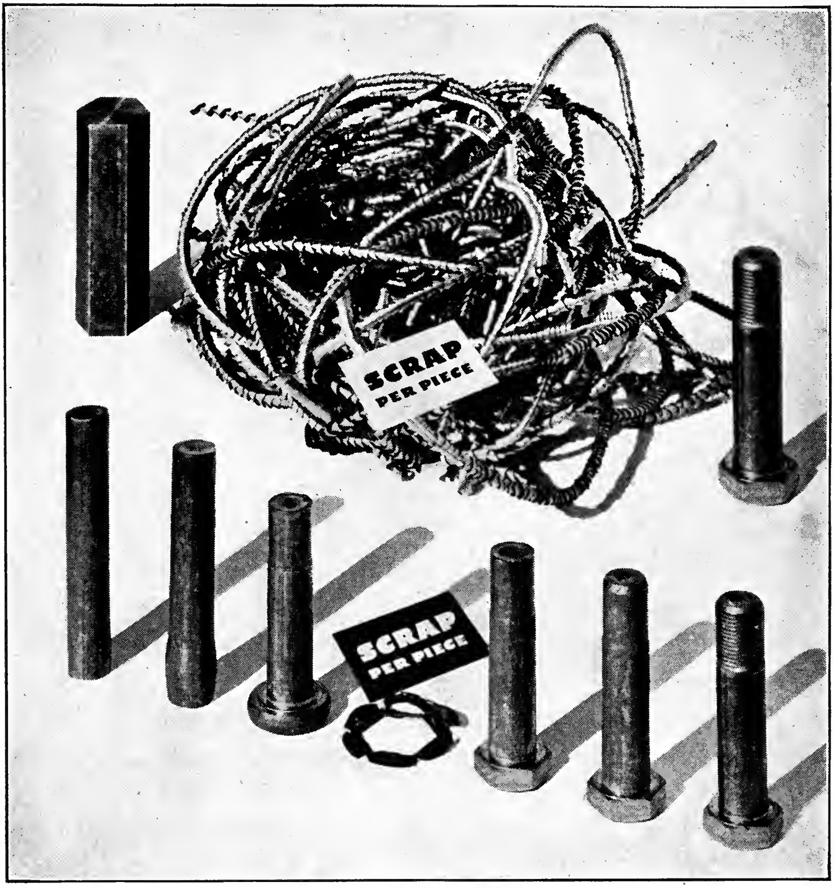



Fig. 15.—Different manufacturing processes can turn out the same product. Production engineers must choose the best means in each case for their particular company. (*Courtesy of Lamson & Sessions Company.*)

limited, at least one manufacturer turned to centrifugal casting. Another example is the choice of cold heading and stamping over machining, as is illustrated in Fig. 15.

**Selection of Machinery.**—In the small plant, the engineer who plans the processing is thoroughly familiar with the equipment available. He can quickly make up a list of the machinery on hand if necessary and from this select the best sequence of operations to make the product. In the larger plants, inventories will be maintained of all the equipment, indicating whether it is free or in use and showing the extent of its present loading. The process engineer should not be limited to use of old machinery. By keeping in touch with the equipment market and analyzing his operating costs, he may make important improvements in production as a result of junking present machinery. When a new product is being processed, some equipment from the outside will undoubtedly have to be secured.

The process engineer is guided from the beginning by the rate of production that is desired. This is the common denominator for all operations and makes the line function as a unit. The length of time the job will last or the total volume to be made actually controls the amount of money he can spend on equipment; but for proper balance of operations the rate of production will be foremost in his mind. Many times the most efficient machine will not be chosen, for it would result in overcapacity. This concept of planning the whole series of machines for a specific rate of output is the major point which differentiates processing for line production from processing for the job-lot plant.

Determining the rate of production is described in Chapter X. It is a very simple calculation involving the working days per month and per week, the hours per day, and the over-all production schedule. It should include spare parts, allowance for spoiled work, and an allowance for safety. Peak-production figures must be considered so that the capacity of the line can handle the maximum rate, for it is difficult to expand fabrication lines once they are set up. Naturally, the number of workers operating any given piece of equipment and the loading and unloading time must be considered in matching equipment capacity to that of the line.

The range of possibility in selecting equipment is great. From handwork to completely automatic machines, all have their place in the line. What equipment the process engineer chooses will, of course, depend upon the nature of the product, the rate of production, and the breakdown of operations possible. His background and ingenuity and the existing equipment in the plant will play an important part. No two engineers will process a job exactly alike. In the machining of simple oil holes in a certain product, three plants of the same company each did the operation differently. Each knew

MACHINE TOOLS REQUIRED FOR 50 PCS/HR FOR THE BOLT OF A 0.30 CALIBER CARBINE

NUMBER OF MACHINE TOOLS REQUIRED

| Starting from— | Bar stock | Forging | Forging | Forging |
|---|---|---|---|---|
| Machine tool | Company *A* | Company *B* | Company *C* | Company *D* |
| Hand screw machines | 8 | 7 | | |
| Multiple drill presses | .. | 3 | 8 | 13 |
| Drill presses | 15 | 8 | 2 | |
| Lathes | 3 | 3 | 5 | 14 |
| Speed lathes | .. | 2 | | |
| Power mills | 19 | 13 | 21 | 14 |
| Hand mills | 15 | 5 | 3 | 2 |
| Spline mills | ... | 1 | | |
| Profilers | 8 | 6 | 3 | 7 |
| Grinders | 1 | .. | 2 | 2 |
| Marking machines | 1 | | | |
| Power saws | 1 | | | |
| Centering machines | 1 | | | |
| Deep hole drill | .. | .. | 3 | |
| Total | 72 | 48 | 47 | 52 |

FIG. 16.—Comparison of four different companies all tooled up to produce at same rate. Note the difference in total machines depending on condition of raw stock. More important, note the difference in type of machine selected to do the job.

how the others were proceeding but felt that its own method was most favorable under the existing conditions. Figure 16 shows a comparison of the equipment required for a certain product as selected by four different companies.

As further illustration, we may compare a shaper and a broach. The shaper may take half an hour to remove the material. By broaching, the metal might be removed in one motion of the tool in less than a minute. While the two machines might sell for the same price, the cost of the cutting tool on the shaper is negligible, whereas the broaching tool might cost several hundred dollars. To sharpen the shaper tool would be inexpensive, whereas the cost of sharpening the broach might approach $100.

Since the equipment in production lines is devoted to one or a few products, it is characteristically designed or tooled for a specific purpose. Specialized, hybrid equipment can be made to meet precisely the desired rate of production. Special-purpose machinery does not always mean line production, but if the quantity is sufficient to justify setting up a line, it is likely, also, to support specialized equipment. One automobile manufacturer remarked upon viewing a number of radial drills in a military tank plant, "An automobile company wouldn't even look at them. One or two might be in the toolroom, but the production equipment would be all multi-spindle stuff."

There is no reason why universal, general-purpose machines cannot be used in production lines; but since they are to be utilized for one particular job, it is usually more expensive to sacrifice speed for the excessive flexibility of universal machines. On the other hand, the process engineer may favor the elaborate, special machine when frequently it is not demanded. One concern found that the process engineer called for an $8,000 machine on a certain milling operation. Slow delivery allowed the company to realize that the job could be done with a few modifications of a standard shaper costing $700. As for flexibility, many manufacturers have turned to equipment of the unit type (illustrated on page 264).

Outside equipment manufacturers may frequently be depended on for determining the processes and machines that are needed. The selection of facilities may be left in their hands, and they will submit a cost estimate of the complete job. Even where the company process engineer handles the work himself, he cannot afford to overlook the valuable ideas which outside equipment builders can offer. An experienced process engineer will know how to obtain and best use this engineering service. But caution should be used in accepting such outside work without critical study of the equipment for performance and appropriateness.

**Tool Design and Gadgetry.**—Once the equipment is decided upon, the problem of tooling the line may result in homespun creations, scientific developments of technical tool experts, or very simple wooden or sheet-metal devices. All jigs, fixtures, or other work-holding mechanisms, hand tools, machine attachments, stops, controls, and often gauges are here included. In many plants this tooling is the chief task of the methods engineer responsible for processing the job. In the larger metalworking shops, a special group of tool designers will develop the tool details with the process engineers. Figure 17 illustrates the magnitude of tooling in a single line. Because of the relatively large quantities of each product being made and the specialization of workers and machines at each operation, thorough study and analysis of the tooling usually prove worth while. To be sure, the problem is different and simpler for hand operations or assembly work than for a fabrication line, but in either case the tooling program will be of considerable significance.

It is not our intention to discuss the techniques of tool design or the principles of motion economy. We want to point out but two facts involving the relation of this work to line production.

In line production the work of motion study should be conducted along with the design of the tools. The chief objective is to build the quality and cost of the job and the skill required into the tools. At the same time, simplicity and ease of operation are highly desirable. Frequently, these two objectives are the responsibility of the same individual; but where this is not the case, some thought should be given to the motions of the operator of the tool *before* it goes into the line. Building the line is too often a piecemeal activity with work simplification appearing after the job is under way. This is not only wasteful, but it leads to unbalancing the line. Moreover, it stimulates resentment between the tool men and motion-study men. Figure 18 shows a set of principles developed by motion

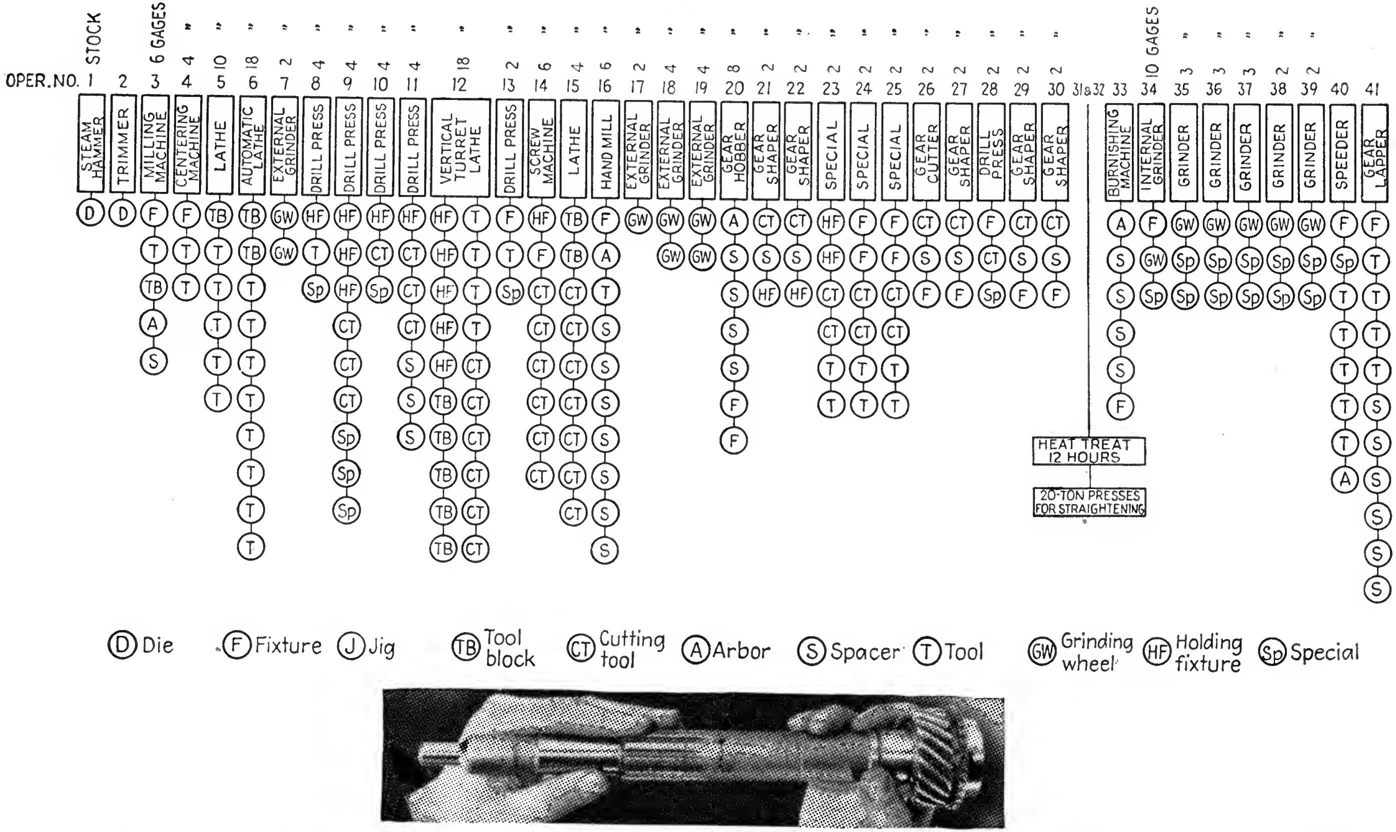



FIG. 17.—Here are shown the machinery and tooling, including gauges, necessary to produce this one part on a production line. (*Courtesy of Automotive Council for War Production.*)

1. Make the necessary movements as short as possible without crowding the operator.
2. Replace hand movement by automatic machine movement where practical.
3. Replace hand movement by foot movement.
4. Eliminate the passing of work from one hand to the other.
5. Provide hand levers, etc., with multiple functions.
6. Use mechanical ejectors.
7. Arrange so that finished work will drop from fixture into discharge chutes. Use drop discharge chutes and the push-through idea.
8. When drop discharge cannot be used, arrangement for disposal directly in front of operator, over top of machine, is often a good solution.
9. Arrange for getting new work from hopper or chute as close as possible to loading point or from location close to discharge point so as to overlap movements.
10. Provide mechanical holders to eliminate the use of the operator's hand as a holding device.
11. When possible keep hand movements within radius of forearm pivoted from elbow. In all events keep within radius of full arm without body bend or twist and without necessity for stepping to reach point desired.
12. Eliminate barriers so that movements can follow shortest path.
13. Keep both hands busy with useful work and avoid waiting of one hand.
14. Provide double station fixtures; one for each hand.
15. Centralize all control levers and starting buttons within the normal work area.
16. Aid locating by means of slides, guides, flanges, stops, bell mouth holes and bullet-nosed pins.
17. Separate scrap from good parts by simple mechanical means.
18. Eliminate all unnecessary use of the eyes. Keep necessary eye use within small space (about six-inch circle if possible).
19. Avoid necessity for operator to assume uncomfortable position. Most of the work should be at elbow level when seated and 6″ below elbow level when standing.
20. Build controls of proper size, shape, and weight, and build to operate without undue effort.

Fig. 18.—Motion economy rules to guide tool designers and process men.

21. Provide for as little upkeep of jigs, dies, fixtures, etc., as the job will allow.
22. Build foot pedals so that they may be operated with comfort by either foot.
23. Where feasible, arrange so that machine can be operated equally well from standing or sitting position. This is best accomplished by arranging to work at 6″ below elbow height when standing, then provide high "posture chair" so that operator may sit and work at elbow height. When foot controls are used, it may be necessary to provide duplicate upper and lower pedals.
24. An operator who is seated can use both feet to operate pedals.
25. Provide definite location for loose tools. Mount, if possible, in position for use to require as little handling as possible.
26. Make all controls "quick acting." Use toggles or cams instead of screw clamps.
27. When work is power fed, close fixture by movement of cam clamp handle against machine frame.
28. Design machines for loading so that loose tools such as pliers, tongs, etc., do not have to be used to place the parts in fixture.
29. Where possible, levers such as feed handles on drill presses and arbor presses should be made reversible so that they can be operated by either the right or the left hand.
30. Design machines as much as possible to shed oil and dirt by eliminating flat horizontal surfaces.
31. Provide sufficient place for chips and turnings and make these places easily accessible for cleanout.
32. Provide sufficient toe space to allow operator to stand up to machine as he should.
33. Provide compound lines large enough to keep chips and turnings washed off fixtures to relieve operator from having to brush or blow off.
34. Provide for easy, simple, and quick tool changes and setup change.
35. Provide for fast feed of tools or carriages up to work and fast return to unloading point.
36. Make the job safe for the operator. Do not sacrifice safety for motion economy but strive for both.
37. Check the hourly output to see that it will not become a "bottleneck" in the line.

(*Courtesy of Saginaw Steering Gear Division, General Motors Corporation.*)

| METHODS AND EQUIPMENT RECORD | REFERENCE | REVISED | NAME OF PART | PART NO. 3600250 |
|---|---|---|---|---|
| TOOL ENG H.G. Warner B.T. DATE 2-4-43 | 15 | 2-15-43 | Tank (Mfg Assy.) - Complete | NO. OF SHEETS 21 |
| | | | MODEL M-5 Light | SHEET NO 16 |

| OPER NO. | OPERATION NAME | DEP'T NO | MACHINE NAME AND NO | TOOL NO | DESCRIPTION OF TOOL |
|---|---|---|---|---|---|
| | BASKET SUB-ASSEM. | | | | |
| 10 | Assem. hydraulic unit to pump | T-10 | Roller Conveyor | 3600250-T-152 | CP #344 RS Impact Wrench<br>Buck for Turret Basket Assy. |
| 20 | Assem. pump unit to basket floor | T-10 | | | CP #344 RS Impact Wrench |
| 30 | Assem. oil pot to basket floor. | T-10 | | | CP #344 RS Impact Wrench |
| 40 | Assem. slip ring assy. to floor | T-10 | | | CP #344 RS Impact Wrench |
| 50 | Assem. conduits to slip ring assy. and motor | T-10 | | | |
| 60 | Assem. switch to conduits | T-10 | | | |
| 70 | Assem. pipes to hydraulic unit and oil pot. | T-10 | | | |

FIG. 19.—Operations lists show the sequence of operations and necessary equipment as determined by the process engineer. This is an exact copy of the original pencil listing for the turret basket subassembly of the M-5 light military tank.

analysts in one concern to guide tool designers. Many other companies require their new tool and process engineers to take a course in motion study.

A second objective is the viewing of all operations in the line as a unit. In tooling, perhaps even more than in selecting equipment, the rate of production dictates decisions. By proper tool design, equipment already on hand can be improved

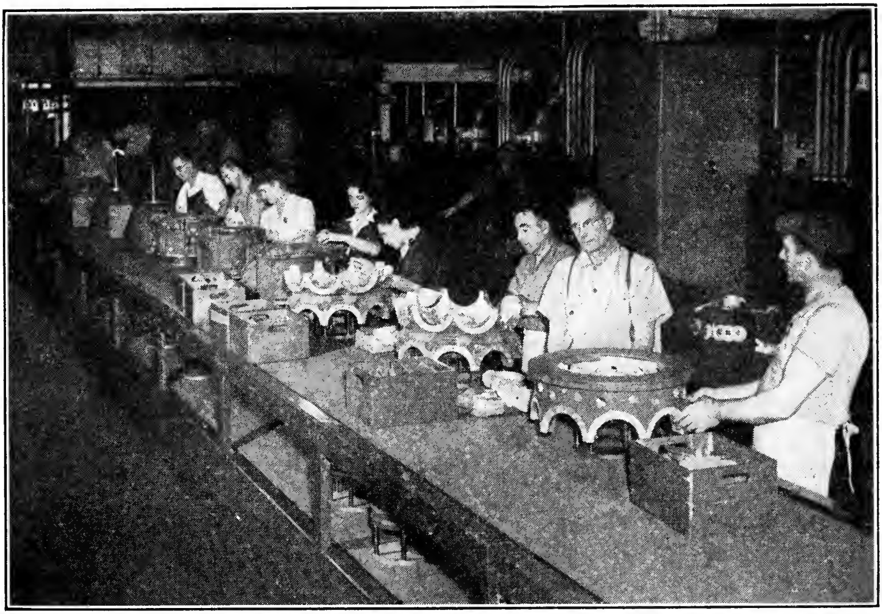


Fig. 20.—This simple belt conveyor line masks out certain areas on these aircraft motor parts before they are painted. Each worker has his specific operations of placing corks, tape, or wood blocks at the points needing protection. (*Courtesy of Ford Motor Company.*)

to meet desired outputs, and a finer balancing of the line can be worked out to secure a uniform operating time at each station along the line. One measure of the effectiveness of the tooling is the degree to which it will permit of the proper balancing of workers and equipment.

**Operations List.**—After the process engineer has worked out the sequence of operations and determined the equipment and tooling that will be needed, he lists these on an operations sheet of some kind. This is done in pencil, with ample room between entries so that changes can easily be made. Names and numbers of the equipment and tools are recorded at this time, as is shown in Fig. 19.

Approval by the chief process engineer is generally secured before the operations lists are typed for distribution to the

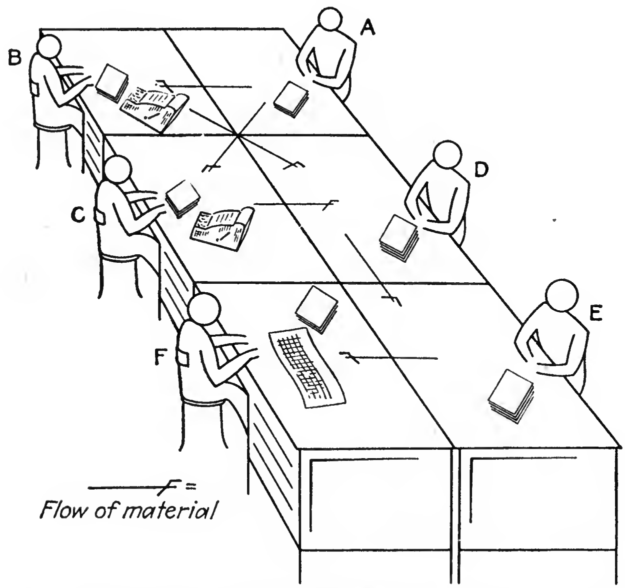



FIG. 21.—Line production in statistical checking of sales reports. The material consists of a pack containing a standard number of sheets, which are passed from one operation to the next. Operating equipment (besides office supplies) includes desks, adding machines, etc. The operations are as follows: 1. Reconciling invoice copies with control sheet. 2. (Operators *B* & *C*) Sorting by class, territory, type of order, etc., and preparation of top sheet for each subdivision. 3. Coding for districts and state. 4. Tabulating special information such as types of product or account. 5. Accumulating list values for each subdivision and posting.

Packs containing 200–250 sheets are most advantageously handled. Where smaller packs are received from field offices, they are held and combined with sheets received the next day or days, except that at the end of the month it is necessary to proceed with smaller packs. Packs remain in the line about three hours; approximately 12 packs are in the line at one time, this number being controlled largely by the initial operator.

Production lines of this kind have operated successfully for mailing, payroll, and similar work.

other production-engineering groups, the production department which is to make the part, machine and tool stores, machine shop, maintenance division, and others. Equipment to be used is so indicated on the equipment-inventory records.

Changes in the method of doing the work from that prescribed in the operations list generally require the approval of the process engineer. In the same way, he may be held responsible for recording on his operations list any changes that occur and for seeing that such changes are put into production at the time called for.

While this process engineering may seem complicated, it is essential that it be followed. Even in elementary lines, such as polishing, burring, paint masking, and office work, as shown in Figs. 20 and 21, every step should be considered.

## EXECUTIVE READING

"Organization and Control of Mass Production," *Factory Management and Maintenance,* Vol. 101, No. 9, p. 97. E. A. Boyan points out the technique of establishing mass-production jobs, with particular emphasis on metalworking manufacture.

"Automotive Design Techniques in Mass Production of Ordnance," *Product Engineering,* August, 1943, p. 467. Suggestions for redesign of component parts in order to take advantage of mass-manufacturing processes.

"Aircraft Production Analysis, Key to Assembly Line Efficiency," Parts I and II, *Aviation,* Vol. 42, No. 11, p. 148; Vol. 43, No. 1, p. 179. Article by L. F. Dorman shows the importance of product breakdown to line production.

"Automatic Tooling Speeds Production in the New Wright Aeronautical Plant," *Machinery,* Vol. 48, No. 6, p. 109. H. E. Linsley describes the automatic machines that are used in aircraft manufacture, making possible the maintenance of close tolerances even with unskilled labor.

"Wright Aero Revolutionizes Engine Production," *Machinery,* Vol. 48, No. 11, p. 141. Similar to the preceding article.

"Airplane Assemblies in Perspective," *Automotive Industries,* Vol. 85, No. 12, p. 24. George Tharratt illustrates systems of breakdown which help in visualizing production.

"Engineering Release for Mass Production," *Aviation,* Vol. 41, No. 7, p. 108. L. N. Pizzuto describes the release system in an airplane plant using both process and product layout.

"Planning the Manufacturing Program," American Management Association, M.P. 1, 1932. R. F. Whisler, J. L. Cochran, and C. E. Hook tell of the path that the product follows from the time it is conceived, through the experimental, model-making, and testing stages to the actual manufacture.

"Production Engineering," John Wiley & Sons, Inc., New York, 1942. A book by Earle Buckingham which surveys the broad field of production engineering.

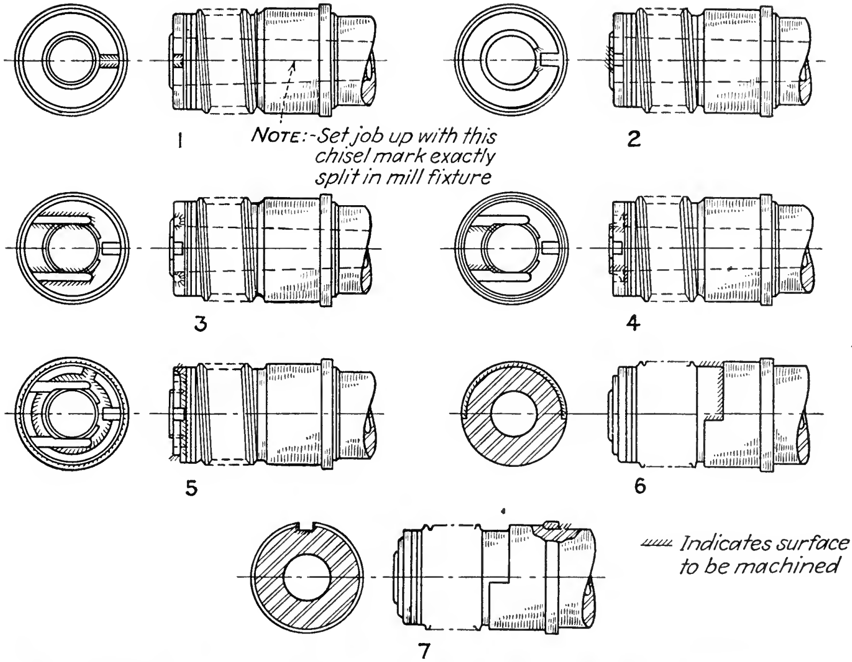
# CHAPTER V

## MOVEMENT OF MATERIAL

Regardless of whether the selection of materials-handling devices is a function of process engineering, motion and time study, or layout, its importance to line production justifies considerable attention. The moving of material is an inherent part of a production line. Because of the location of each operation adjacent to its immediate predecessor in the line, the material generally moves only a short distance, and much unnecessary handling is eliminated; thereby, marked reductions in transportation costs are made possible. Yet, with the breakdown of the work into a greater number of operations, as is clearly shown from Fig. 22, the number of handlings of each piece is increased. The high volume being produced also emphasizes the importance of material transport. In the selection of handling equipment, emphasis should be focused on the line as a unit. Too often each operation is analyzed separately, and a handling device peculiarly suited for one operation is selected, without consideration of its appropriateness in relation to the entire line.

### HANDLING DEVICES

There are any number of mechanical transporting devices: powered or hand trucks, trackless or rail carriers, elevators, hoists, cranes, portable racks, and a variety of conveyors, all of which may be used in production lines. In the case of line production housed in one machine, that particular machine is largely built around the conveying mechanism. Here several operations are performed with no intermediate handlings. Machines such as the eyelet machine, Bullard Mult-Au-Matic, or Gridley type automatic lathe are of the indexing variety, while the Ingersoll or Newton continuous millers, as well as



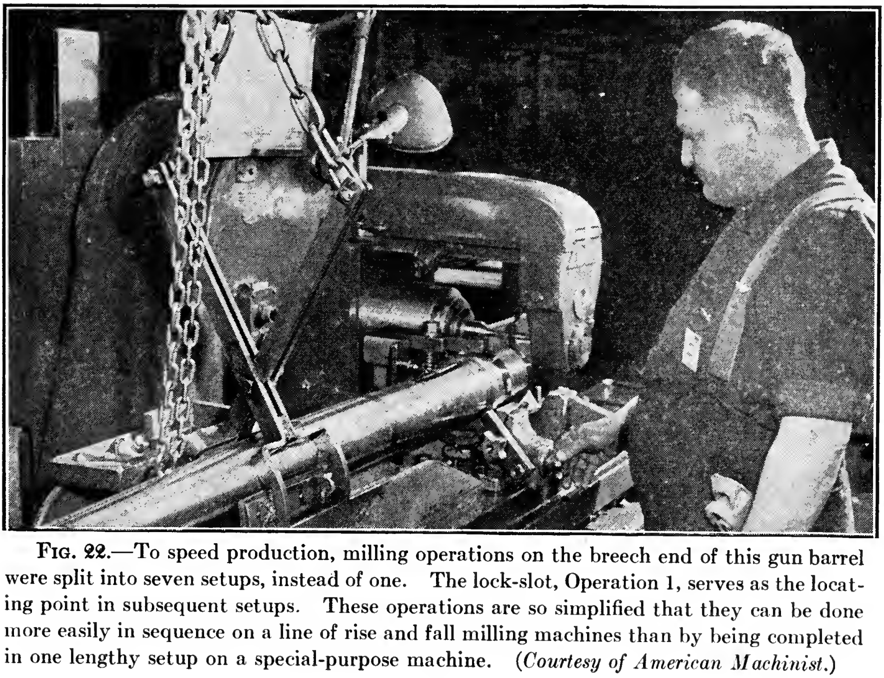



FIG. 22.—To speed production, milling operations on the breech end of this gun barrel were split into seven setups, instead of one. The lock-slot, Operation 1, serves as the locating point in subsequent setups. These operations are so simplified that they can be done more easily in sequence on a line of rise and fall milling machines than by being completed in one lengthy setup on a special-purpose machine. (*Courtesy of American Machinist.*)

certain grinders and polishing machines, exemplify the continuous motion of parts through a sequence of operations taking place in one machine. The movement through equipment of this sort is somewhat different from the movement along a line consisting of several machines or work areas.

Again, the movement of material between lines and to and from the lines is a problem apart from movement on the lines themselves. The flow of work in the line is dependent upon the delivery of material to the production line, and the two must be coordinated; otherwise, goods in process stored at the line have to be increased abnormally to ensure continuity of flow. Material may be delivered by almost any kind of transporting and carrying device, usually of a more flexible type than the means employed on the line itself, inasmuch as it may be more economical to have several hours' supply delivered at one time. Frequently, timetables and standard routings for delivery trucks can be precisely established. In other cases, delivery conveyors may be controlled to feed parts to the desired point continuously or at proper intervals. In any event, the material handlers or stockmen are normally held responsible for having material at the line as it is needed.

**Movement on the Line.**—Where the movement of the work on the line is integral with the equipment, a transporting device may still be the basis upon which the line is constructed. The Greenlee automatic transfer machine shown in Fig. 23 is an example. Here a number of machines are so mounted as to become one machine. Other continuous automatic lines of equipment in which the handling device plays the major role include bottling lines and sequences involving such operations as degreasing, rustproofing, spraying, dip painting, baking, cooling, rinsing, draining, drying, plating, and polishing, which are particularly adapted to conveyorization. Figure 24 shows such a continuous processing line. On lines of this nature, the operators are largely machine tenders.

In contrast to automatic transport is the simple passing of work by hand or gravity from one operation to the next. This method of moving the material is frequently the best. There are, unfortunately, many instances of conveyor installations which were later discarded in favor of hand passing. It may

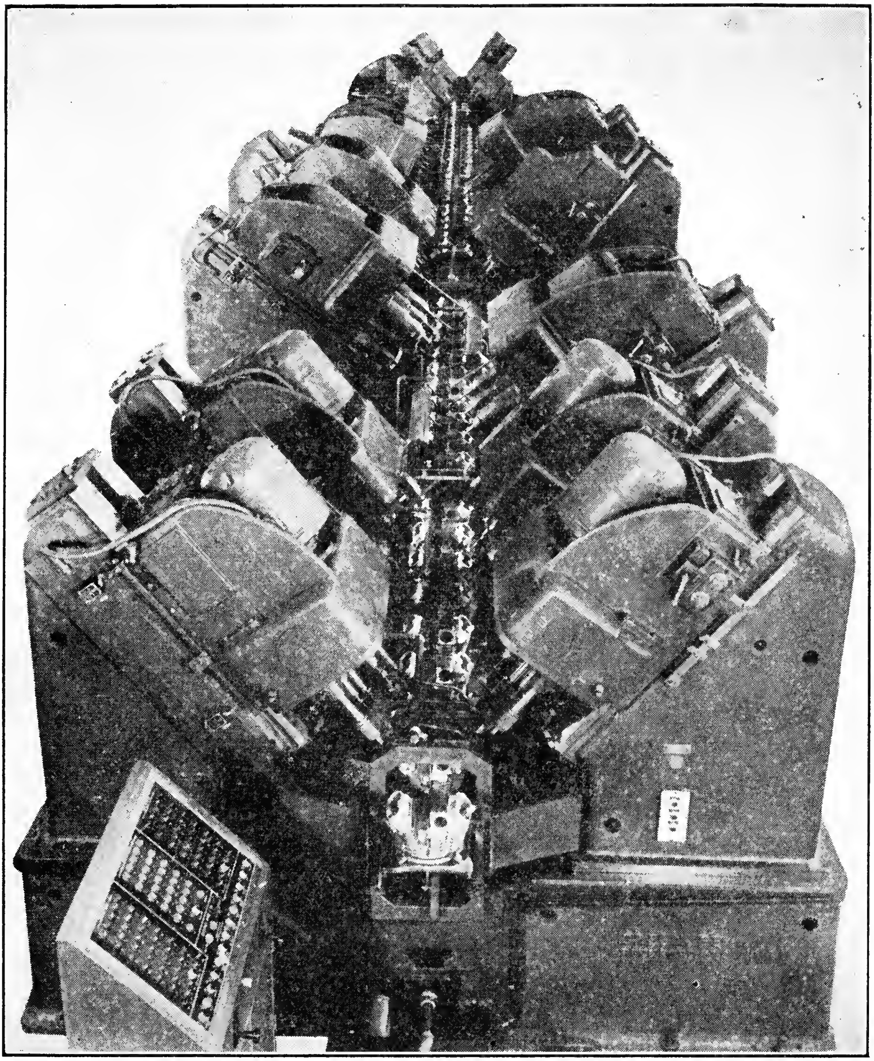


FIG. 23.—This multiple station line at work on aircraft cylinder heads consists of several machines closely integrated about a conveyor. The work is firmly fixed to the transfer mechanism and all units move simultaneously one station at a time. The multiple spindle drills actually perform on three units in three stations at the same time. (*Courtesy of Wright Aeronautical Corporation.*)

be much easier to slide the work along a bench than to place it upon, and remove it from, a transporting mechanism. Com-

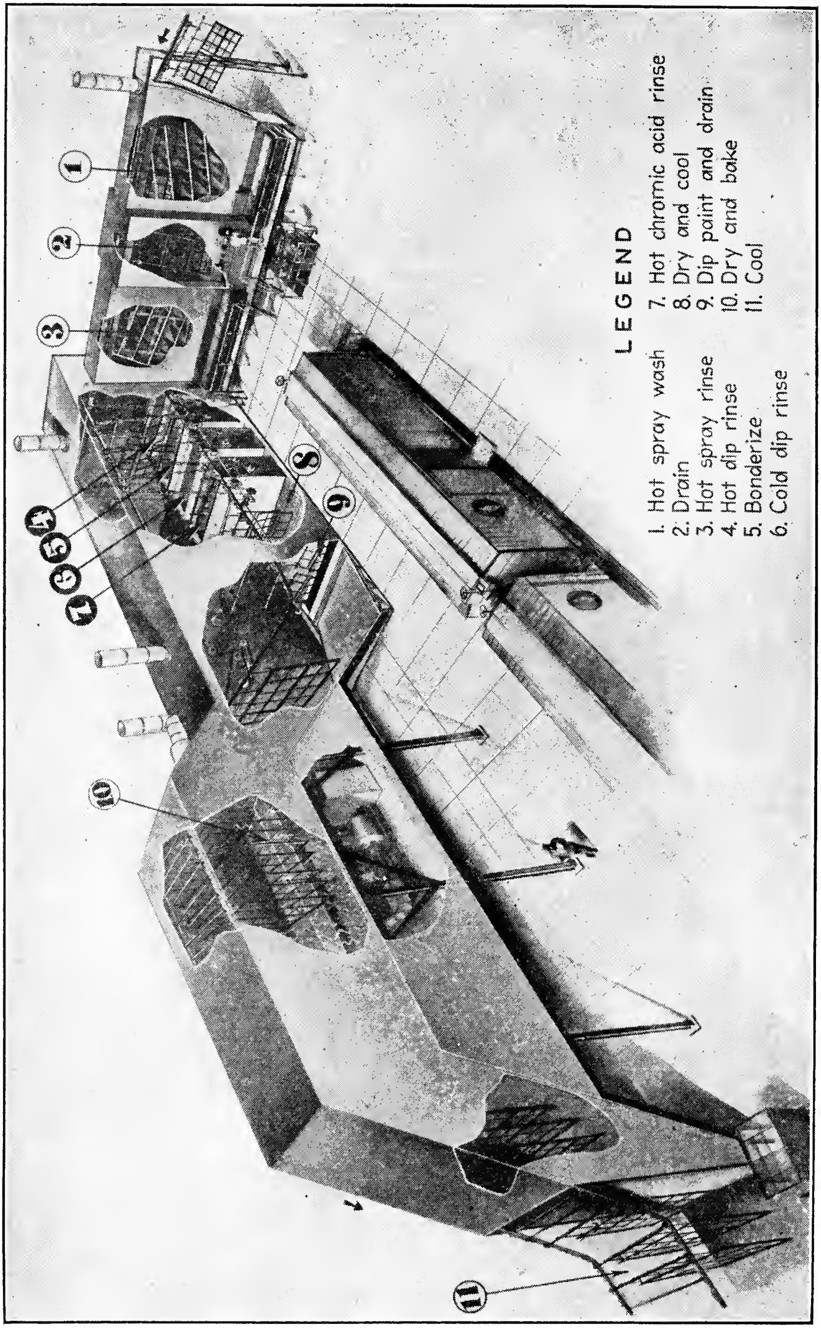



Fig. 24.—Automatic handling in this continuous processing of steel window sections means that the entire line is based upon the mechanical transporting device. (*Courtesy of Truscon Steel Company.*)

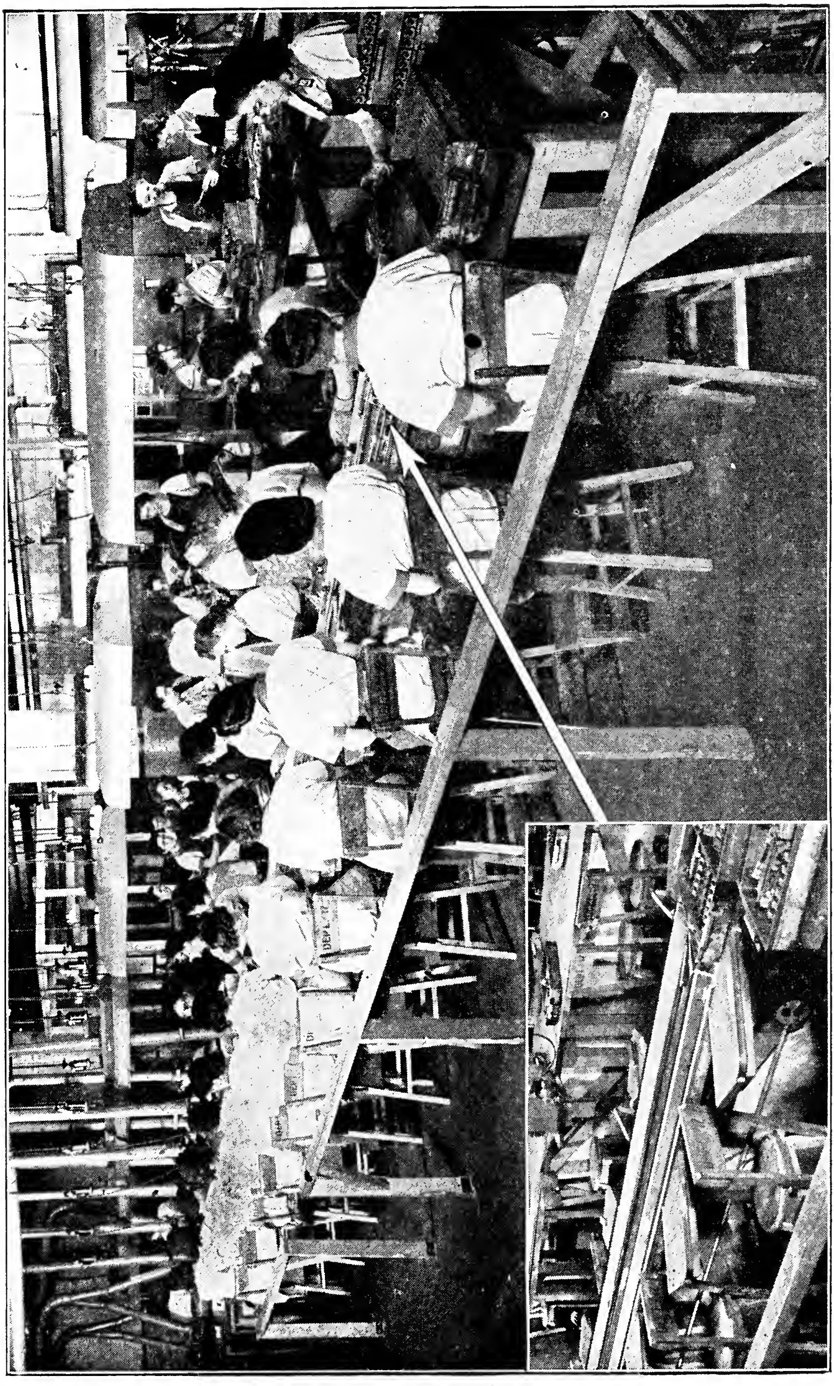


Fig. 25a.

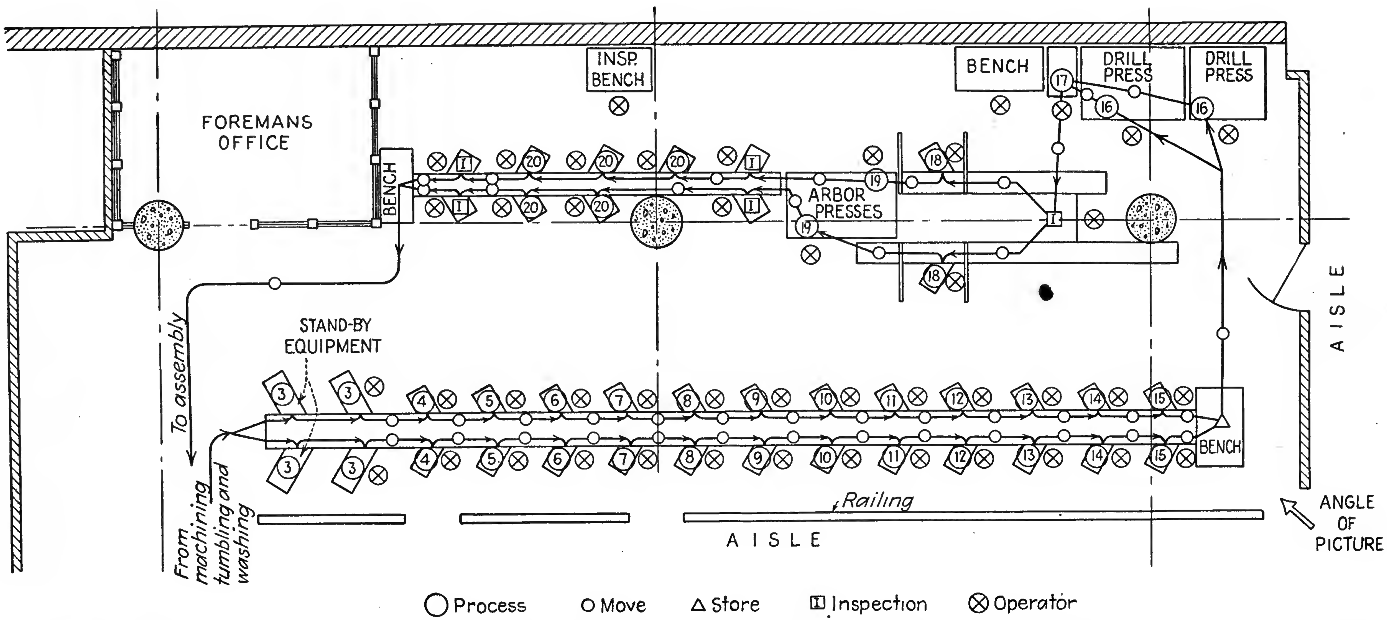
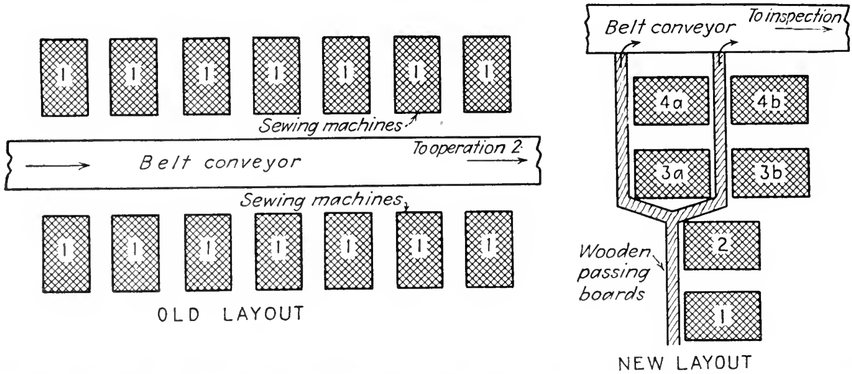



FIG. 25b.—This simple line performs all burring operations on a small gun component. The work is slid along a metal channel from operator to operator. Insert on Fig. 25a shows this with operators removed. The operations indicated on this flow diagram are listed in Fig. 25c.

| Operation no. | Operation description | Number of employes per operation | Equipment and tools used |
|---|---|---|---|
| 1 | Tumble receiver | 2 | Roto-finish tumblers |
| 2 | Wash receiver | | Detrex washer |
| 3 | Buff each side of rear end for Rockwell test, both sides of dovetail and both sides for slide guide | 2 | Buffing lathes using 6 in. sewed buff (two lathes as stand-by equipment) |
| 4 | Pencil grind inside magazine opening | 2 | Kipp or Aro grinders |
| 5 | Pencil grind barrel edge, cartridge ramp, and radius at ramp | 2 | Kipp or Aro grinders |
| 6 | Pencil grind undercut in slide guide and rear end of bolt guide slot | 2 | Kipp or Aro grinders |
| 7 | Pencil grind front end of bolt guide slot and mechanism opening | 2 | Kipp or Aro grinders |
| 8 | Polish cartridge ramp | 2 | Kipp or Aro grinders |
| 9 | File burr at rear end of receiver | 2 | 6 in. pillar hand files |
| 10 | File to gauge *.XXX* dimensions on rear lug | 2 | 4 in. pillar hand files |
| 11 | File dovetail for sight base to gauge | 2 | 4 in. taper hand files |
| 12 | File *.YYY* dimension on *T* slot in rear lug | 2 | 4 in. extra narrow pillar file |
| 13 | File dimensions *.ZZZ-.WWW* on *T* slot in rear lug and fit to relation gauge | 2 | 8 in. mill hand file |
| 14 | File front lug to gauge and file radius at magazine opening | 2 | 8 in. mill hand file |
| 15 | Gauge magazine opening and file when necessary | 2 | 6 in. rat-tail and 6 in. pillar files |
| 16 | Finish ream spring hole and gauge 100 per cent | 2 | Walker Turner drill press |
| 17 | Finish ream trigger housing retaining pin hole and gauge 100 per cent | 1 | Walker Turner drill press |
| Inspect | Check threads and depth for qualification of barrel | 1 | Thread qualifying gauge |
| 18 | Pencil grind radius on edge at rear of cam and front end of bolt lock slot | 2 | Kipp or Aro grinders |
| 19 | Shave rear of cam opening and bolt lock slot | 2 | Hand arbor presses |
| Inspect | Check alignment for bolt lock | 2 | Alignment gauges |
| 20 | File burr from shave operation. File to blend step on cam opening. File cam opening to fit plug gauge | 5 | 6 in. knife and 6 in. pillar files |
| Inspect | Visual inspection for burrs | 2 | None |

Fig. 25*c*.

panies usually find it profitable to consider use of gravity chutes, sheet-metal slides, and bench or portable floor carriers before considering more elaborate devices. The burring line shown in Fig. 25 uses practically no aid to handling. Mechanical transport is not a necessary characteristic of line production.



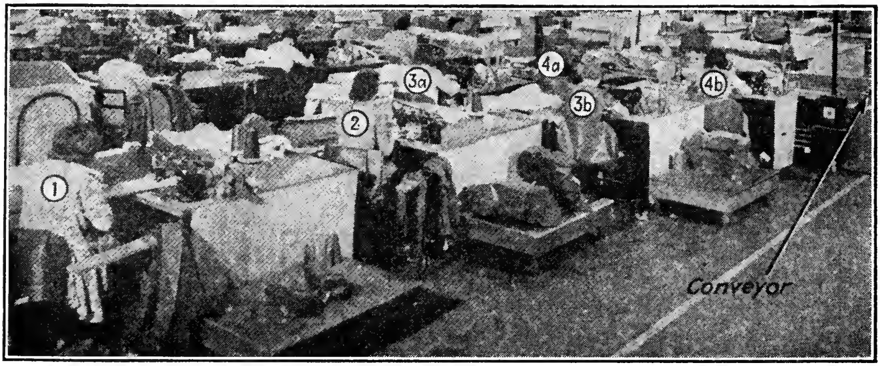




FIG. 26.—All but one conveyor was eliminated in this stitching department by changing from functional layout to line production. The new arrangement has several similar lines parallel to each other. The old layout had sewing machines on each operation lined up along the conveyors. (*Courtesy of Factory Management and Maintenance.*)

The accompanying diagrams and picture, Fig. 26, illustrate how hand passing eliminated a large amount of conveyor transport. Here the four operations were performed in functional areas, operators in each area working alongside a belt conveyor. After rearrangement for line production, only one conveyor is used to carry away the finished goods. The material in process is merely slid along a board built around the machines.

On the other hand, much of the advantage of one installation was lost because a manufacturer failed to understand that one of the chief savings of line production lies in reduced handling. His equipment was arranged in sequence, but between each two machines was room for three skid platforms —one skid being loaded, another being unloaded, and an extra skid so that there would always be work on hand. The skids held several hours' work of stock, and operators had to lift and lower the material a considerable distance. Moreover, lift trucks were still required to move the skids. Some simple handling device would obviously have been much more effective.

Occasionally, both stock racks and conveyors are used in the same line. This is usually evidence of interruptions in the flow. The mere presence of surplus stock racks after the installation of a conveyor does not justify their use. Production men favor the building up of banks of material as protection, but this practice, also, can be carried to an extreme. Under certain circumstances, extra racks may be desirable at bottleneck or critical operations. Additional racks can also be used to keep separate from regular production special orders for extra requirements.

## TYPES OF CONVEYORS

Conveyors have been classified in many ways. They may be fabricating or assembly conveyors, fixed or portable, scheduled or nonscheduled, straight or circular. Again, they may be classified as powered, nonpowered, or gravity conveyors. The powered type may be subdivided into those which are powered for continuous operation and those which operate intermittently.

Perhaps the most common method of classifying conveyors is according to their physical characteristics:

*Overhead monorail conveyors* are generally chain-driven and support a variety of hooks, racks, platforms, or special carriers.

*Roller conveyors* may be powered, level, or gravity.

*Chain conveyors* of the drag-chain variety move the parts, dollies, or fixtures along the floor or bench; those of the cross-bar type support the parts or push them along.

*Flat conveyors* may be of several types, including apron, plate, platform, wire mesh, wood slat, and belts either with plane surfaces or cleats.

*Chutes* and *slides* are of various kinds.

## THE USES OF CONVEYORS

Conveyors themselves have a great many advantages which have been listed and discussed in other places. These advantages all hinge upon the four basic functions which conveyors perform—transporting, pacing, work-holding, and storing.

As a *transporting* device between operations and to and from the line, conveyors can be of value in reducing handling. They can feed material to the workspace, pre-position it so as to eliminate extra motions by the operator, and quickly take it to the next operation or line. Where processing can be performed on parts in transit, conveyors can pass the parts through ovens or acid baths at a rate geared to that of other operations on the line. This permits better working conditions than manual processing. Conveyors can also be used for removal of scrap and other purposes.

As a *pacing* device, the conveyor is unique, though uniform rates of production can be obtained without it. A powered conveyor paces each operation to assure a steady optimum output. Moving at a uniform speed, it enables parts to be scheduled from storage at precisely calculated time intervals. It holds the workers at their jobs and requires them to perform their work in the time allowed. It enables them to build up a rhythm and enables management to discern quickly any bottleneck operations. To some manufacturers, pacing is the chief advantage of line production, and it is their aim wherever practical to get the job on "paced production." The hazard here is that, if any one of these operations is not completed on time or if the work is spoiled, all subsequent operations may be delayed or wasted on defective material.

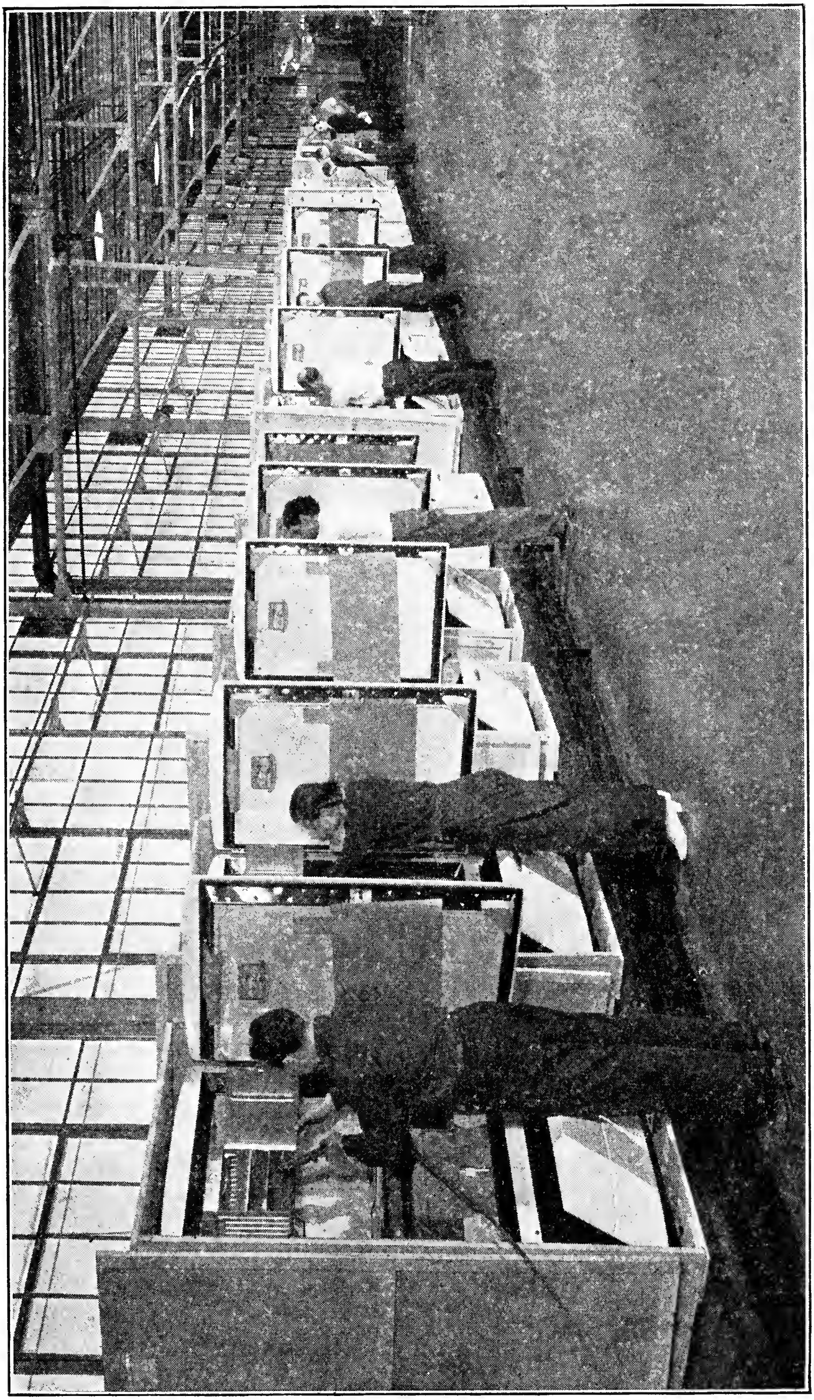


Fig. 27.—Installing freezing units on this line is done with the refrigerator held right in its crating material. With continuous movement of the line, operators must walk along with the work. Compare this with Fig. 55, where workers ride on the conveyor itself.

As a *work-holding* device, conveyors (with or without fixtures or dollies) permit work to be performed with a minimum of manual handling, thereby reducing the major nonproductive elements of each operation. Figure 27 shows finishing operations being performed while the product is held in its crate on the conveyor.

As a *storing* device, conveyors allow parts to be raised from the floor so that they require no floor space and are less liable to be broken, lost, or soiled. Conveyors may support a temporary storage as a cushion between operations. Conveyor sidings can be used to store parts with resultant decrease in the time required to supply the line.

### THE SINGLE PIECE VS. THE LOT

The reverse of line production occurs when one individual makes each complete part and assembles the unit. This condition is rarely found in industry today. Throughout this book, we constantly refer to the job order or the job lot, or to functional layout or layout by process as the opposite method of manufacture to that of line production. The term *job lot* has the connotation that an established quantity is made up at one time, all pieces traveling together through the functional departments in a lot. Yet line production can also handle groups of parts; each piece need not necessarily be transported individually.

Large, heavy, and valuable work pieces will usually be handled singly. Here the number of pieces on the production line should be held to a minimum. When work is moving on the line in lots, pieces at any given operation must remain idle, waiting for their lot to complete the operation. In such instances, the longer the operating time, the greater is the desirability of transporting each piece individually rather than in a lot. Again, where the piece remains in a working fixture through a series of operations, it is ordinarily moved individually, especially when the fixture is attached to a conveyor.

Group transport may be used when the parts are small, easily damaged, odd-shaped, or difficult to handle, so that a rack or holding device is required. A further advantage is that drying times between operations can often be cared for automatically if parts are handled in lots.

The nature of the process also affects the decision to handle individually or in lots. In the spreading of rubber cement on the lips of certain parts, it is common to arrange them in overlapping sets of several pieces and then to cement all at one time. They may even be held in the set until dry and until two or three coats have been applied. Where motion study has found that a series of operations at one work station can be performed more quickly if several parts are worked on together, the parts are likely to be moved to the next operation in this same grouping. Spot welding and the use of impact wrenches or powered screw drivers are examples of operations that are often done by first positioning a number of pieces and then fastening them all as one operation. Similarly, in profile milling or flame cutting or in aligning several identical parts the work is often handled in multiple-piece setups.

Many times, parts are handled on a line both singly and in lots. Where this is the case, it is wise to locate together all operations where the parts are handled in lots, preferably at the beginning or end of the line. This usually minimizes the return handling of any empty containers.

Special containers may be constructed to hold the desired number of pieces in a given lot. The size of lots will, of course, vary with conditions, but containers passing through the same operation should each carry the same number of pieces. Where several different types of containers are used on the various fabricating, subassembly, and assembly lines, the number of pieces per lot on each line should bear a relation to the lot sizes on other lines; thus counting is greatly facilitated, and the joining or dividing of lots at junction points of lines is simplified.

## REMOVAL VS. NONREMOVAL OF WORK FROM CONVEYOR

If the conveyor is to pass directly through the work areas, the operation in some instances can be performed best without handling the material in any way. This condition applies to such operations as spraying, dipping, cleaning, and heat treating. Operations which are performed while the piece remains on the conveyor require that the parts be firmly positioned in some holding device so that operators may use both hands to advantage. To remove the material at each operation from

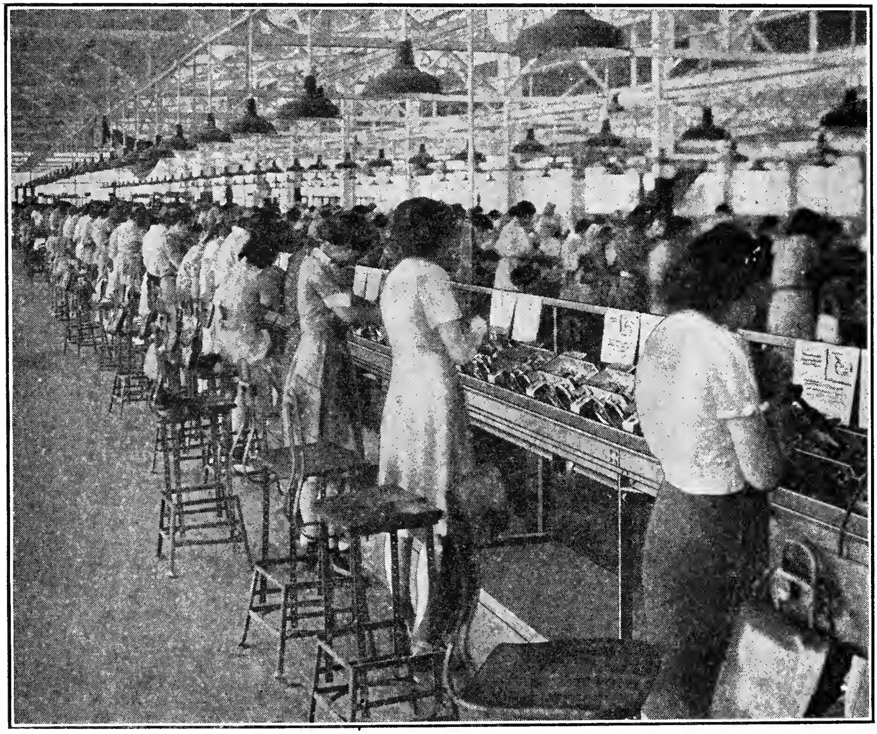


FIG. 28.—On this conveyor are mounted special fixtures to hold the radio chassis in position while the assembly operations are performed. (*Courtesy of Logan Company and Radio Corporation of America.*)

the conveyor shown in Fig. 28 will be impractical. Moreover, management may not want the material removed from the conveyor because of the difficulties in controlling line inventories, the possible delays caused in subsequent operations, and the likelihood of parts getting lost or by-passing certain operations. With most heavy and bulky parts, such as automobiles, aircraft, refrigerators, and machine tools, the units are too large to permit removal to a work area beside the

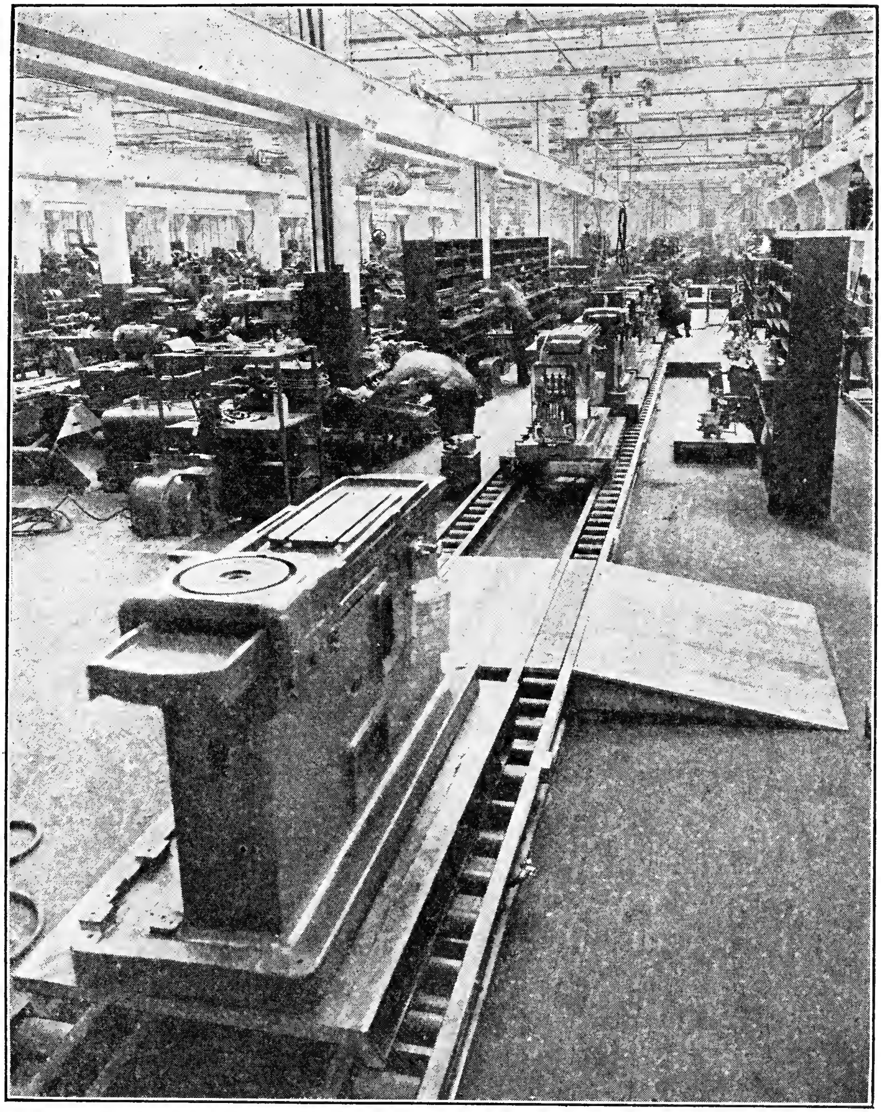


Fig. 29.—Roller conveyors and skids used to transport machine tools in assembly. At the end of the line a lift truck runs between the conveyors and picks up the complete machine on its skid. View is from starting end of line. Note bridge to allow crossing the line. (*Courtesy of Heald Machine Company.*)

line. This can be seen in Fig. 29. To withdraw even small parts requires a certain amount of unproductive handling time which will greatly increase the proportion of nonproductive activity in operations of short duration. Motion-study engineers are quick to detect this disadvantage. They also watch for excessive reaching when the conveyor does not carry the work into the normal working area of the operator.

Other similar inconveniences may be obviated so that workers need not remove parts from the conveyor. Tools may be supported on balancers or springs so that they are within easy reach or may be merely "dropped" after each operation. Working heights may be readjusted. For example, floor platforms, tiers, scaffolding, and the like may be introduced where it is inconvenient to raise or lower the work on the conveyor. Pits are fitted into the floor on automobile assembly lines so that underneath work may be done more easily.

Yet small parts and those having operations of relatively long duration are often taken from the conveyor at each work station. Operations that are to be performed in machines or working fixtures located beside the conveyor will, of course, require removal of the piece. Again, where the part on the line is not easily accessible or requires inconvenient working angles, it had better be taken from the conveyor. Obviously, the types of holding devices, tools, or gadgets that can be used in relation to the conveyor will be important in any decision to remove the work. When the work is returned to the conveyor after an operation, the parts may or may not be replaced in the same position, depending on the speed and movement of the line. Material that must be returned to a specific spot can be so placed as the next piece is removed. Thus every space on the conveyor is always filled. The operator in this case may hold two or three pieces in his work area so that he always has one ready to place on the conveyor, even if he is delayed on one piece.

## CONTINUOUS VS. INTERMITTENT MOVEMENT

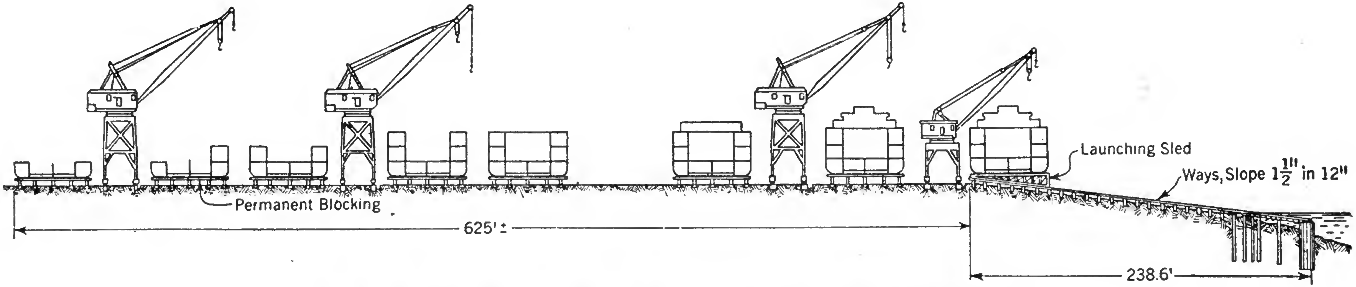
The conveyor itself may move continuously or intermittently. The pacing value is greatest when the work moves continuously, yielding maximum automatic control and minimum supervision of the line. With continuous movement, the worker is constantly reminded how far along on his operation he should be. From the standpoint of conveyor cost, those with uniform speed are generally cheaper. Continuous movement is well adapted to situations where the work is presented to operating equipment such as circular cutters, millers, heating flames, or paint guns.

Certain factors favor intermittent motion. Operations may thus be performed statically without unloading and loading. Immobile pieces of equipment, such as dust-collecting tubes, fixed testing panels, and special lighting, may require parts to remain at rest during the operation. This condition applies also to larger assemblies where air or welding leads are brought into the unit. The filling of bottles and most packaging operations are performed on an indexing type of machine, though there may be continuous motion between machines. Here the conveyor must be able to slip along under units that are stopped. In situations where it is too expensive to install a powered conveyor, as on the assembly line shown in Fig. 30, the material will necessarily move intermittently.

The student of motion economy naturally favors the indexing type of motion. The operator is saved awkward reaches at the beginning or end of his operation, and he does not stand in order to move with the work. The work will always be pre-positioned in the correct place so that he need not grope for it. Moreover, practically all manual operations can be completed more easily on stationary work. These objections are overcome to some extent in continuous flow if the workman moves with the work, on the conveyor itself, on the fixture or holding platform, or on an adjacent conveyor such as a chair mounted on wheels in a track on the floor.

## RECOGNITION OF PARTS

A particularly annoying problem is encountered on delivery conveyors carrying more than one part, and on line conveyors with more than one worker at each operation—namely, the difficulty of material recognition. Unless the work can be



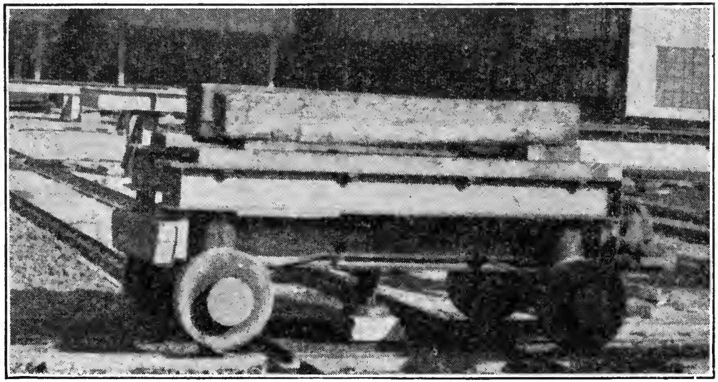



Fig. 30.—Section through a shipyard showing seven berths and the launching ways. Hulls are moved between stations by means of 16 transfer carriages traveling within channel tracks mounted on a concrete runway. Hydraulic jacks attached to the carriage as shown raise the hull; a cable powered by an electric hoist shifts the hull to the next position; and when the jack is released the hull is lowered onto new blocking. The carriages are then rolled back to the next hull and the operation repeated. Each hull is moved one position, leaving No. 1 berth vacant for a new keel. (*Courtesy of Dravo Corporation.*)

readily identified, operators may miss some pieces while losing time on others in duplicating the handling or operation already performed. Probably the best solution here is some means of automatically stopping or discharging the work in front of the operator. Automatic stopping mechanisms and a variety of

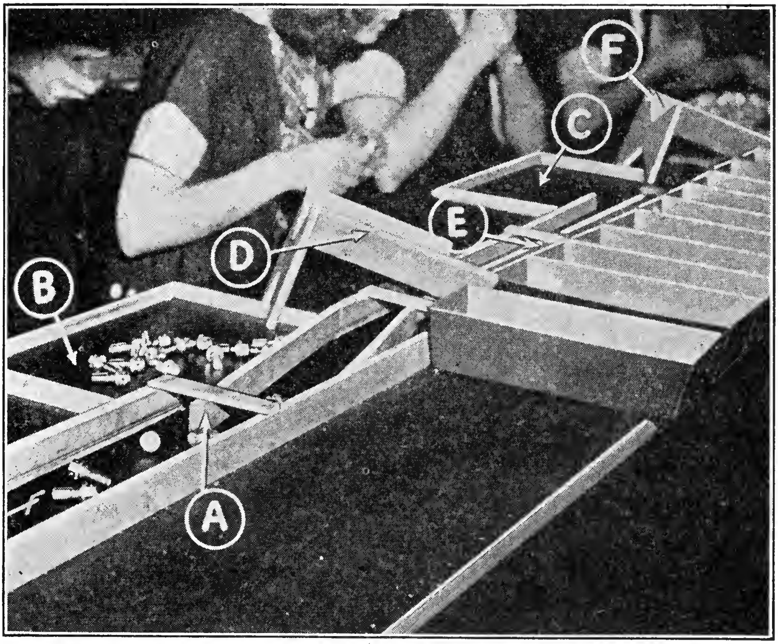



Fig. 31.—Double stations are provided for on this inspection line by a wicket at point *A* which divides the parts between stations *B* and *C*. Parts inspected at station *B* are dropped into chute *D*, which releases them to channel *E*, and the belt carries the parts to the next operation. Parts inspected at station *C* are dropped into chute *F*, which also releases them to channel *E*. Boxes at the right hold the classified rejections. (*Courtesy of Iron Age.*)

trips, catches, and guides may be used to advantage. In consequence, the operator is not distracted constantly by having to watch the conveyor in addition to performing his operation. Figure 31 shows an attempt to use guides and chutes for automatic identification of parts.

The example in Fig. 32 shows an arrangement used in one electric appliance plant. The number of workers at each operation varies. By means of simple wooden guides placed over the belt conveyor, units are accumulated at each station in correct amount. As the units travel down the conveyor, they are picked off by a pointed guide in a way that distributes the work evenly to each worker.

Where control devices cannot be used, the worker must rely on positioning of the piece and on tags, colors, or other markings. Sometimes it is practical to use a double conveyor, each side or level of which is used alternately between operations. Multiple-shelf carriers may similarly be used, the operator merely being instructed to remove the work from

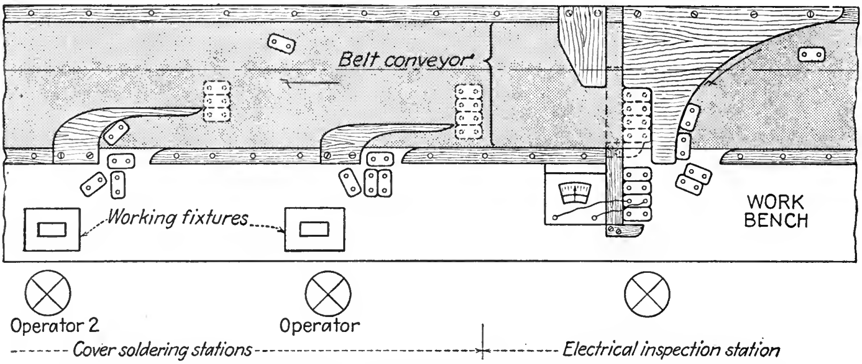



FIG. 32.—Balanced distribution to the proper workers is automatically accomplished on this line. The electrical inspection operation is four times as fast as the soldering. After testing four units the inspector releases them all at one time by means of the sliding device. Parts are picked off at each of the cover soldering stations. When the units are soldered, operators return them to the far side of the conveyor belt. (*Courtesy of Markus & Nocka.*)

shelf 2 and return to 3. In one installation making artillery shot, there were four positions on each conveyor hanger. The shot could be placed right side up or upside down in any of the four places; thus there were eight different positionings.

Tags frequently require close examination and are easily lost or soiled. Colors and markings, on the work, holding device, or conveyor itself, are usually superior. The number of identification combinations that must be worked out is equal to the least common denominator of the various number of workers on each operation. In Fig. 33, for example, any of 12 different combinations may be called for, as there are operations worked on by one, two, three, and four men. Where four workers are required, each takes a piece with his assigned number. Where two workers are sufficient, each is assigned two numbers—one and three or two and four. One operator works on every piece. For three operators, a system of coloring is added. One of the three colors is placed on every

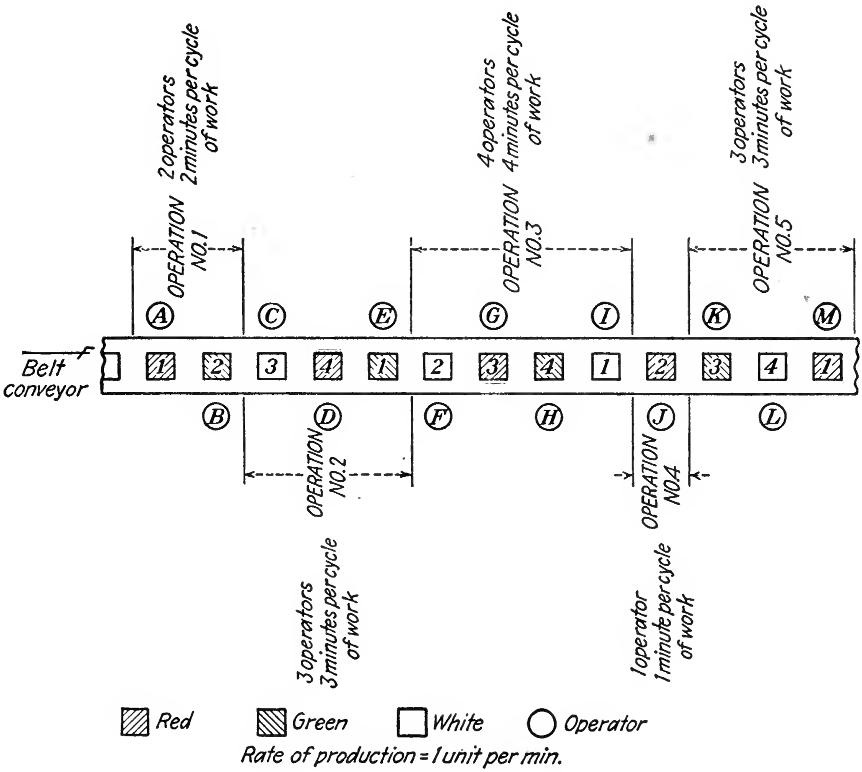



FIG. 33.—Marking of conveyor or moving fixtures allows easy identification of each operator's proper work and permits balancing of workers as shown. Operator *A* works on pieces marked 1 and 3; operator *C* on all white markings; and operator *F* handles every piece marked 2.

third piece in proper sequence. Operators in groups of three ignore numbers and merely look for their assigned color.

## CONTROL DEVICES AND ACCESSORIES

Conveyor installations may be equipped with a number of control devices. A typical installation is motor powered with variable-speed drive, magnetic starter, and start-and-stop push buttons. These push buttons may include reversing or indexing (jog-forward) buttons. The motors may be fireproof, sparkproof, or watertight.

Power drives at various places along a conveyor allow use of a much lighter chain or cable. Multiple drives maintain a uniform pull, difficult to achieve on a long delivery conveyor with variable loadings at different points.

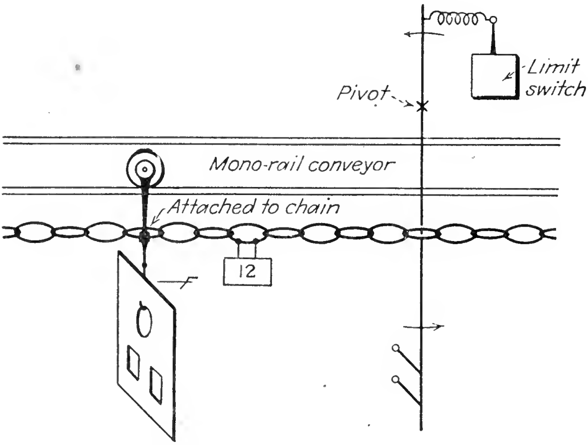



FIG. 34.—When the work strikes the lever the switch is activated mechanically to cut off the power for the conveyor. The tag on the chain is colored to show the position of unloading and numbered to aid the handlers at the stock bank to load for proper delivery sequence.

Many conveyors are automatically controlled by such devices as limit switches and electric eyes. The limit switch may be of the lever type or may be directly connected, and there may be any number of mechanisms on the outside of the housing to provide the control wanted. Figure 34 shows one method of connecting a limit switch. These switches generally work through a solenoid brake which stops the motor as soon as the current is shut off. The electric eyes cut the current as soon as the beam is invaded. These controls are shown in Fig. 35.

Conveyors equipped with these automatic stopping devices run at a relatively high speed and are automatically stopped when they feed up to the desired point. These control devices may also be used as safety measures to stop the conveyor if parts are positioned improperly or if something goes wrong in the line.

Some delivery conveyors carrying several items have control devices placed at intervals to control a different item at each point. Usually, the items which do not actuate any control mechanism will be carried in larger amounts than those which are controlled by a stopping device. In this way, when

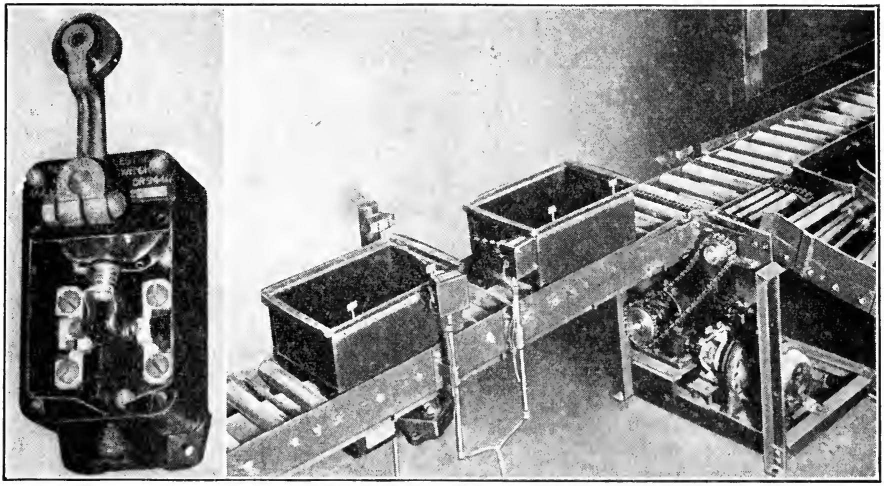


FIG. 35.—The figure at left shows a limit switch (cover removed). The photoelectric relay at right is used to dispatch tote pans to the proper work stations. (*Courtesy of General Electric Company.*)

the conveyor is stopped, there will always be at other working areas material which is within easy reach of the workmen.

Shear pins have been used successfully in localizing the breakdown on conveyors. Automatic devices to prevent overloading are proving even better, for they not only save the time required for the replacement of the shear pin but allow more rapid location of the jam or difficulty which caused the shutdown.

Conveyors of almost any type may be equipped with a variety of turntables, guides, and automatic transfer or discharge devices. Bells, lights, and horns may be used as warnings to signal maintenance men or as signals for moving the line when there are intermittent movements.

Many different kinds of hooks, carriers, portable fixtures, dollies, trucks, tote boxes, stock racks, or special carriers may be designed to support the work in conjunction with conveyors. A number of different containers or racks may be used in the same line. Devising these carriers is an area where savings often greater than those accomplished through tooling can be made.

Practically every handling problem is different, and the ingenuity of the production engineers in this respect is important.

### EXECUTIVE READING

"Storerooms on the Move," *Factory Management and Maintenance*, Vol. 99, No. 5, p. 61. Frank Elwell, the works engineer of the Buick Division, General Motors Corporation, Flint, Mich., gives details of the use of conveyors in an automotive-parts plant.

"How Packard Motors Improved Handling Methods," *Mill and Factory*, Vol. 17, No. 2, p. 27. D. G. Baird points out the various handling methods that may be used in an automotive plant.

"No Man-made Moves Here," *Factory Management and Maintenance*, Vol. 99, No. 4, p. 45. S. L. Meyer, the director of the Finished Goods Department, Calvert Distilling Company, Louisville, Ky., describes work as it is done on the bottling and packaging lines at a distillery.

"Modernization Doubles Departmental Manufacturing Capacity," *Mill and Factory*, Vol. 28, No. 1, p. 92. W. L. Curry tells of material handling and layout for flow in the manufacture of transformers.

"Ford Production Methods," Harper & Brothers, New York, 1936. Hartley W. Barclay includes many excellent photographs of mass-production equipment and layouts.

"Modern Materials Handling," John Wiley & Sons, Inc., New York, 1932. S. J. Koshkin considers in detail all handling equipment, with Chapter XI of particular interest to the line producer.

"Materials Handling," Prentice-Hall, Inc., New York, 1943. Harry E. Stocker treats of the principles and methods of handling all types of material, with no special emphasis on line-production methods.

# CHAPTER VI

## LAYOUT

Although there are many important features in line production other than that of plant layout, it is basically the arrangement of equipment and work areas that distinguishes line production as a method of manufacture. Probably the ideal layout is an arrangement of the plant and its facilities so that the material to be processed is moved a minimum distance and with a minimum of effort, and so that both men and machinery are employed to the fullest extent within the limits of satisfactory working conditions. A well-planned line should at least approach this ideal.

In the arrangement of the plant as a whole, the various production lines should be laid out so that they will feed the final assembly line most easily. Each production line should function first as a part of the complete assembly plan and then as an operating unit in and of itself.

The sequence of operations and the equipment required largely determine the layout of any line. In addition, the layout of any production line is further determined by two activities to which the material must be subjected, namely, material handling and material storing. The method of handling the material and the space needed for handling frequently dominate the layout plan, a fact noted in the preceding chapter. Storage is especially important since it is much more decentralized in line production, usually being located close to the line. The major considerations to be weighed in laying out a production line are sequence of operations, equipment to be used, method of handling, and size and location of storage areas.

There are other features which must, of course, be considered. Existing building structures are often limiting.

Floor strengths, ceiling heights, location of columns, walls, aisles, drains and outlets, and ventilation and exhaust systems are all factors to be considered. For this reason it is easiest to make a layout for an entirely new plant. In the heavy chemical industry, where flow of material reaches its maximum, the entire plant is constructed around an almost ideal layout. In manufacturing, the laying out of lines should still follow the old principles of planning the layout around the processes and planning the building around the layout; or, at least, the more practical limitations should be considered only after the ideal arrangement is worked out.

Line layout involves so many features that it demands more coordination than any other activity in line production; for it affects all persons responsible for both establishing and operating the line.

## LAYOUT FOR ASSEMBLY AND FABRICATION

The location of the end of each line directly at the point of subsequent usage is generally desirable in laying out any space for line production. This makes it necessary to work backward from the point where the line ends and to fit the production operations into the room available. In any new arrangement, it must first be decided from what point the complete assembled unit will be shipped. This decision will locate the end of the final line. With both the end of the line and the point of material receiving fixed, the general flow within the plant can then be determined. The subassembly lines are planned to meet at the proper points along the final line, and the smaller feeding lines join the subassembly lines where these parts are used.

Short transfers are particularly desirable for large, heavy parts. Smaller parts can be stored and moved to the line periodically, where they are again stored until used. Many times a lengthy delivery conveyor can connect two distant lines as effectively as if they were adjacent to each other, though it is more expensive. Yet even here a protective supply of parts is generally held. Thus the layout engineer plans the arrangement so that assembly lines can feed directly into others, or he makes provision in his plan to maintain adequate stock at each point of usage. For the fabrication line, greater space is allowed for storage at the beginning of the line and between operations rather than at points along the line.

The layout of production lines for assembly operations is easier than for fabrication. In the latter case, the sequence of operations established by the process engineer and the machine selected for each operation are the controlling factors in the arrangement and floor space required. In the actual positioning of the machines in a fabricating line, the layout engineer works with information concerning the manner in which the machines will be loaded and unloaded; spaces which need to be kept clear for servicing the machine; and the location of the machine in relation to any conveyor which may be contemplated. When the operations are of a technical nature, his jurisdiction is usually limited to transportations and storages. In assembly, men and small tools can be moved along the line easily, and operations can be readily rearranged, combined, split up, or simplified. This mobility of the actual place in which the operation is performed allows leeway in layout.

Another limitation in laying out fabrication lines is the necessity of grouping parts and therefore the lines by the type of material; steel, cast-iron, or aluminum machining operations must often be kept together because of chip salvage, dust, and the like. This grouping limits the layout engineers in feeding parts directly to the assembly lines. The restriction is not of major importance, however, for it is generally good practice to separate fabrication from assembly.

After the lines have been set up for a minimum of handling and maximum ease of flow, the functional, or process, departments will be planned. This category includes miscellaneous machining, and fabrication or assembly operations, such as heat treating, fast screw-machine work, and punch-press operations, that cannot easily be placed or balanced in a line. These are usually the last departments to be laid out, because the number and variety of parts being made here require only general-purpose machinery which may be altered more readily in accordance with technical requirements disclosed during the final stages in organizing the line.

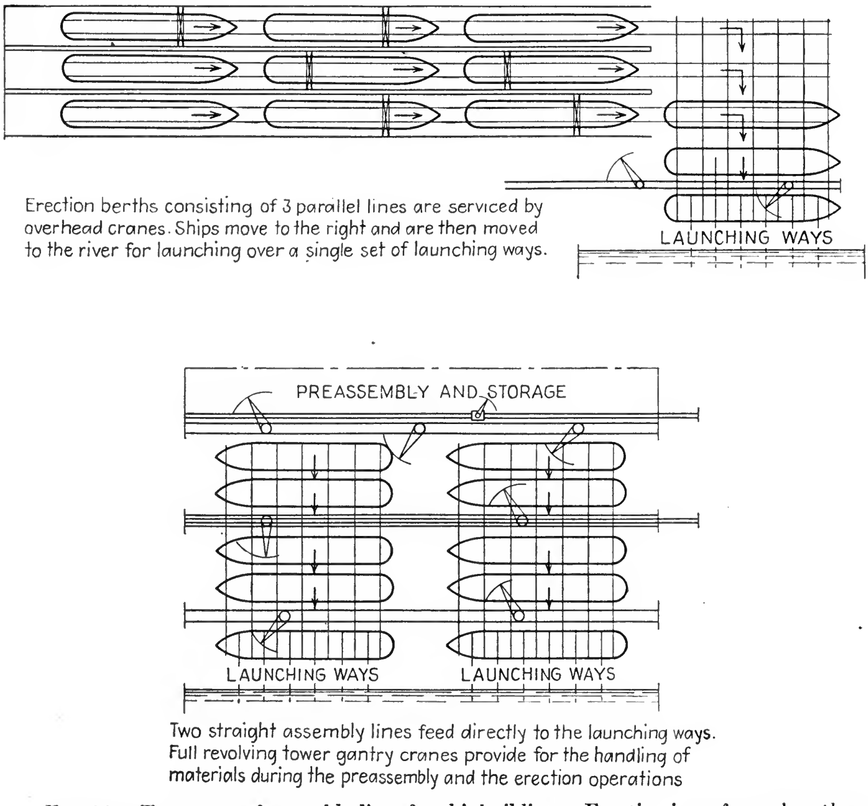



FIG. 36.—Two types of assembly lines for shipbuilding. Erection is performed on these lines, each hull being moved to occupy a minimum of time on the launching ways. (*Courtesy of George F. Wolfe and Society of Naval Architects and Marine Engineers.*)

## LAYOUT AND BUILDING DESIGN

The aim in laying out a complete plant is an uninterrupted flow of material through the various essential processes and operations. This flow can be vertical, taking advantage of gravity. Here the food industry is perhaps the most typical example. Manufacturers have used the multistory structure to advantage by locating the ends of feeding lines or storage areas directly above the points of usage and allowing gravity to simplify the transportation problem.

The flow within any one line is ordinarily horizontal. For this reason, most of the companies operating large production lines prefer the one- or two-story building. In considering the question of land values, building costs, and problems inherent in the specific site, manufacturers should recognize that the lower building offers a reasonably large amount of floor space on one level so that lines may be easily rearranged with fewer obstructions and limitations. Companies experienced in operating lines generally favor a large building where the operations are all kept under one roof instead of being spread throughout several buildings. They also favor a building that is basically square or rectangular, thus permitting a flexible layout and ease in interchanging departments. This is a definite advantage, since considerable change is likely in any line-production layout. Certain lines demand long stretches or open areas for feeder lines. Long, narrow buildings are satisfactory for straight-line assembly, but square areas allow conjoining systems of feeding lines and related layout arrangements.

Production lines for very large parts may require a special structure adapted to the particular product. On occasion, no building at all is needed, as the layouts for ship construction in Fig. 36 indicate.

In layout of smaller lines, the kind of building used is less fundamental so long as a reasonable degree of flow between lines and departments is obtained.

It is common practice to lay out production lines parallel with the structural supports of the building; thus it is easy to mount piping, electric or compressed-air lines, welding machines, or conveying equipment along these supports. Where cranes are used, the line must be laid out with a definite relation to the structural members. Ceiling heights and truss loads must be considered in planning any layout, particularly where overhead conveyors are to be used.

## LINE LAYOUT FUNDAMENTALS

**The Straight Line.**—Basically, the straight-line layout, as illustrated in Fig. 37, is the best arrangement for flow of material. It is simple and allows a systematic arrangement of equipment and work areas. Moreover, most conveyors are easier to install in a straight line, and there are no problems of transfer from one line or conveyor to another. Only when specific limitations exist is any other shape of line desirable.

Figure 37-B shows the crossing back and forth of work between two parallel rows of machines. This is a compact arrangement and allows operators to tend more than one work station with ease. Where a conveyor or stock rack is used in

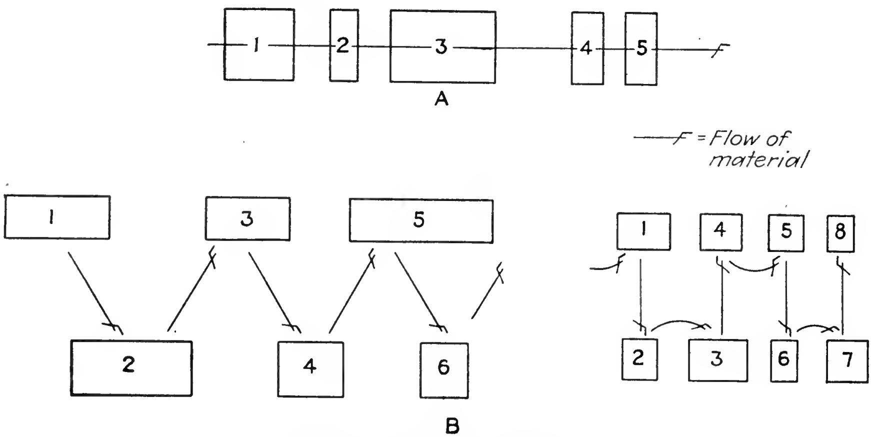



FIG. 37.—Straight-line layouts.

the aisle and the work is placed on it after each operation, as in Fig. 38, it is often just as easy to handle the material from two sides as from one.

A conveyor or other obstruction in the aisle makes it difficult for workers to cross over from one row of stations to the other. Similarly, where two lines are placed back to back so that the operators face each other, as in Fig. 39, it is impossible for an operation on one side to be combined for balance with an operation on the opposite line. If each operator is fully occupied at his station or is in balance with operations in his row of work areas, the back-to-back layout has few limitations. Where operators can work on a unit from only one side of the line and where there are several parallel lines, a back-to-back arrangement will save considerable floor space.

The use of duplicate lines in making the same or similar products has certain advantages. When the volume is too large for one line, a duplicate line will be needed. For the same output, two lines allow the length of each to be half as long, and the operations are broken down to half as much detail. Duplicate lines allow much greater flexibility in

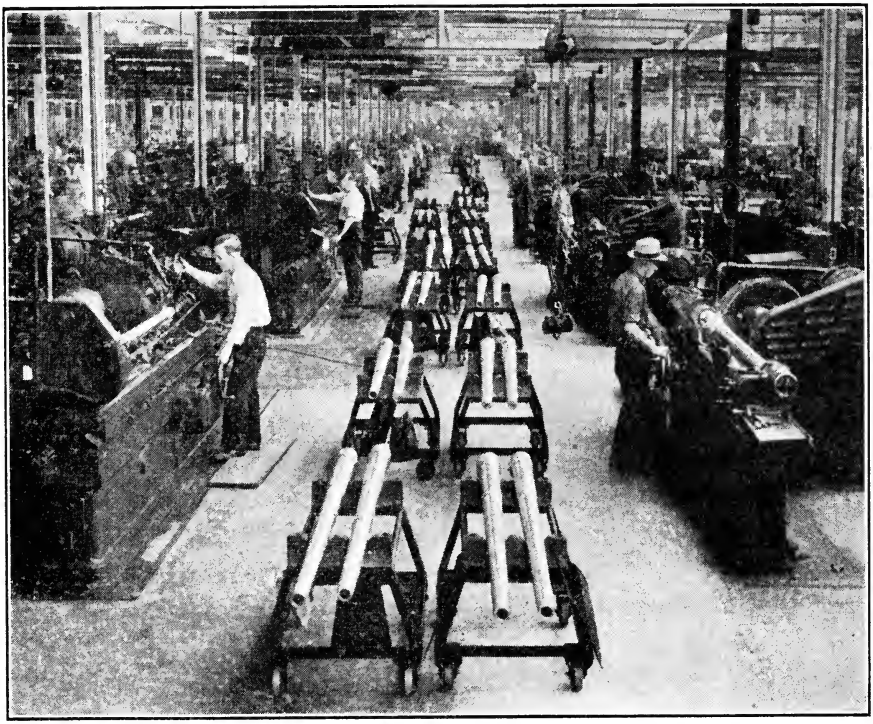


FIG. 38.—Straight-line layout with in-process inventory (float) between the two rows of machines. (*Official U. S. Navy Photograph.*)

changing over to new designs, in adjusting output, and in running special orders. Too many operations in any one line often make for inefficient use of floor space.

**U-shaped Line.**—Figure 40 shows the U-shaped line. This arrangement lends itself to compactness, allowing easier supervision than a long, straight line. The U-shaped line is especially good for fabrication and small assembly work where the line begins and ends at the same aisle. In this case, the handlers have less trucking and handle the stock only at the aisle which feeds and receives the stock. Where the material must enter and leave the work area by the same door or elevator, a U which fills the room is ideal. Any variety of U-shaped line may be made with consequent possibilities for saving floor space, as shown in Fig. 41. Moreover, where certain operations are repeated in the same line or are common

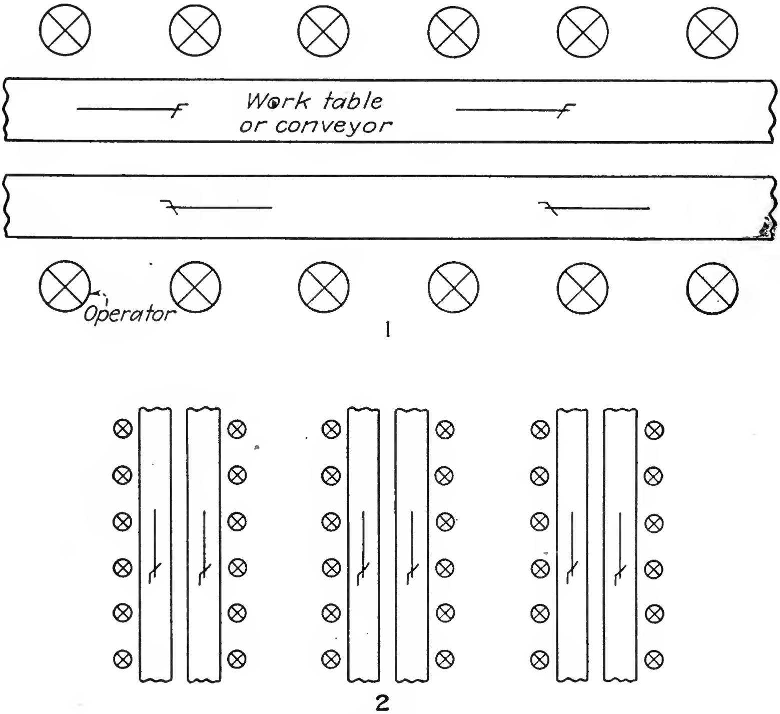



Fig. 39.—Parallel-line layouts.

to more than one part, these lines may double back to meet such a situation.

Among the disadvantages of the U-shaped line are the close quarters of the operators, opposite, behind, and beside each other. Workers know almost at once when trouble develops along the line and, anticipating a rest, their speed and efficiency drops, even though the cause of the delay is remedied in a matter of seconds. Because the operators are grouped closely, there is some tendency to casualness, inattention, and horseplay. The U-shaped line cannot be used where parts or subassemblies are continuously being fed into the line at various points. But where stock racks are located in the center

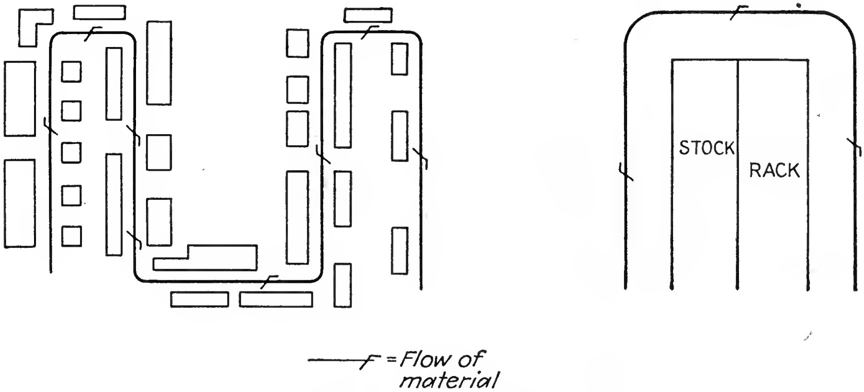



FIG. 40.—U-shaped lines.

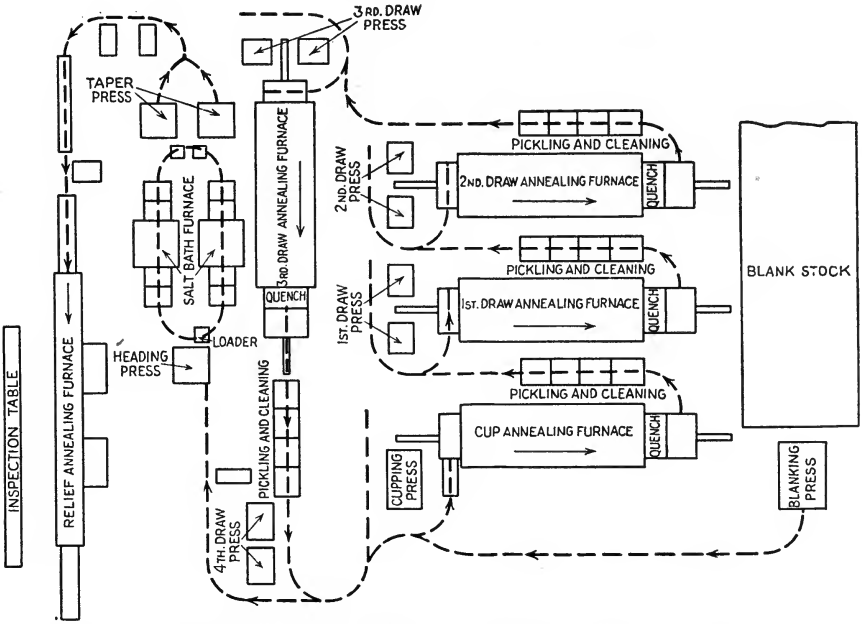



FIG. 41.—This layout of equipment for the manufacture of shell casings is in a combination of U's. Dotted lines indicate flow of material. (*Courtesy of Continental Industrial Engineers, Inc.*)

of assembly U's, the U is entirely satisfactory. Figure 42 shows workbenches located within the U. It should be noted, also, that the delivery of stock, however small, to these storage racks usually means that the stock truck is backed in or out, or the material is carried into the U from the aisle.

**Circular Line.**—The so-called "circular line" may actually take almost any shape so long as the ends are joined, as Fig. 43 shows. Turntables and elaborate merry-go-rounds are

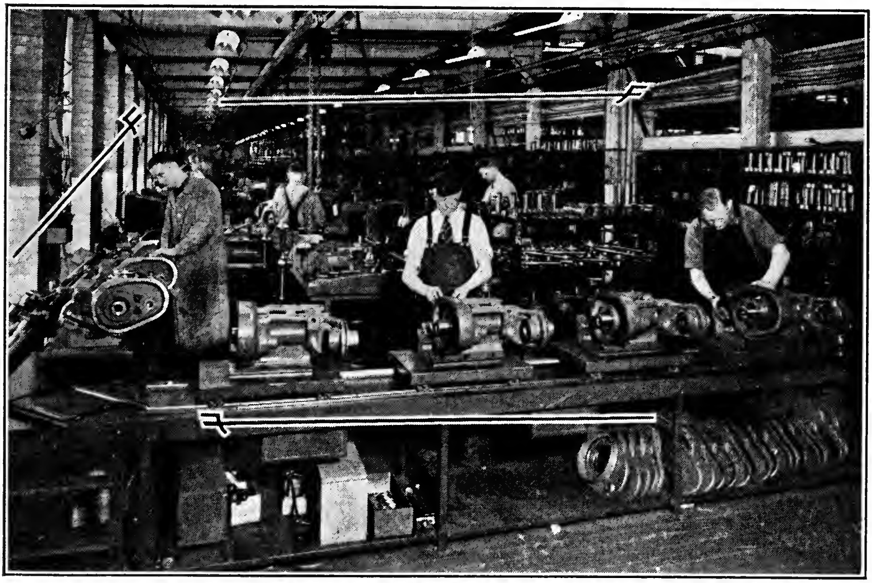


FIG. 42.—U-shaped line for subassembly of head-stocks. Note the track and turntable (lower left) for easy handling of the work on the line, and the workbenches and stock racks within the U. (*Courtesy of Norton Company.*)

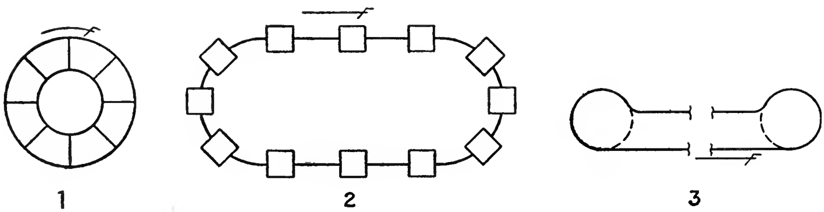



FIG. 43.—Circular layouts.

both circular. *Carrousel* is the name applied to the conveyor of the type that travels back on itself in this way. Like the U, circular lines frequently allow the storage of stock and performance of operations inside the loop. The kidney-shaped line is used when the space inside cannot be so employed and yet the radius at the end must be large.

This endless type of line is commonly associated with a conveyor of some kind, for its greatest advantage is the return of work fixtures or containers to the starting point—often a major problem. Straight conveyor lines often circulate the worktable and fixtures by having the returning portion under-

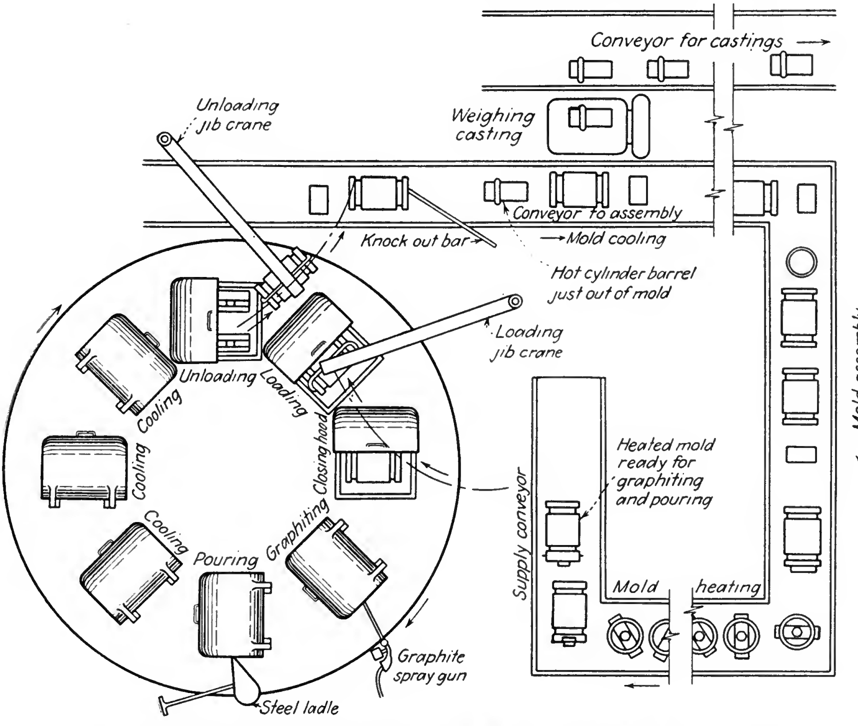



FIG. 44.—A double circular layout for centrifugal casting of engine cylinder barrels. The eight-station turntable at left has facilities for closing hood, graphiting, pouring while mold is rotating, and cooling; as well as loading and unloading. The second line on a roller conveyor takes away the molds after shake-out, relines and preheats molds, and supplies them to the turntable. (*Courtesy of Aviation.*)

neath the working level of the conveyor. However, when these fixtures are large, it is impossible to return them in a vertical plane. In addition, with horizontal circulation each fixture will be loaded full time, thus requiring fewer fixtures and a smaller length of conveyor. Figure 44 shows a combination or double circular layout.

The circular line is used, also, where connections are attached to each unit for several stations. Steam for vulcanizing, air for inflating, or electricity for testing or heating when used in line production can be fed more conveniently from the center of the merry-go-round. Circular lines lend themselves

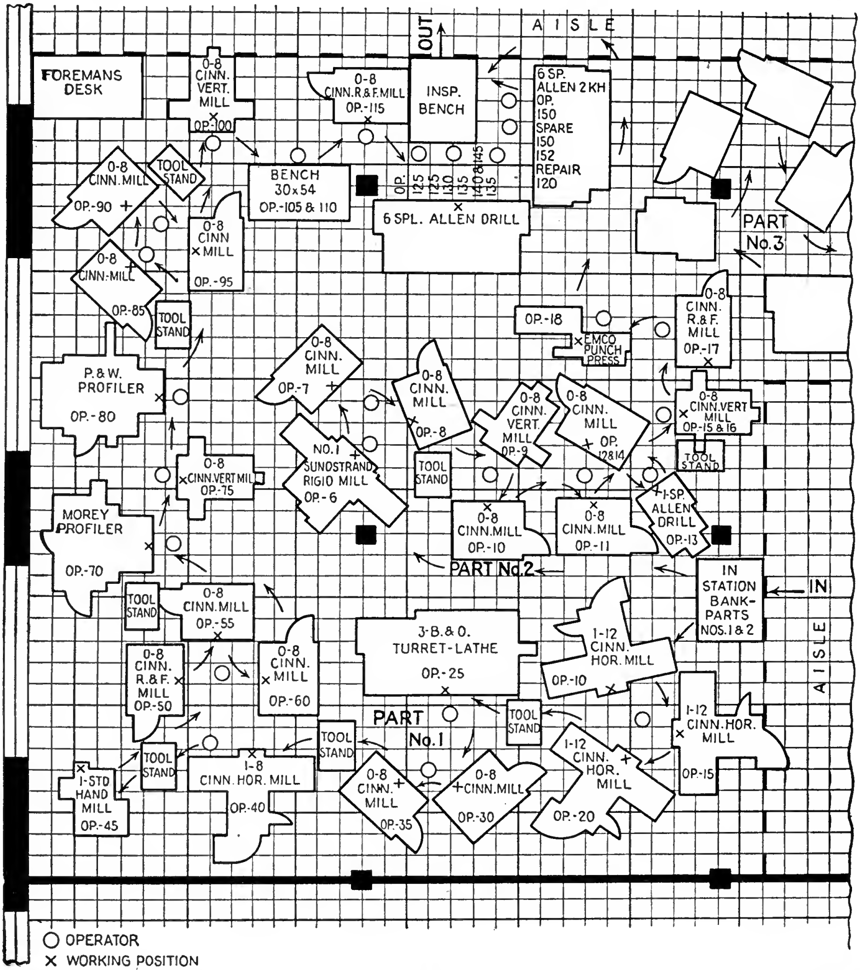



FIG. 45.—The odd-angle arrangement of equipment on these small-parts machining lines reduces materials handling and increases the effectiveness of worker operating time. Parts are passed in pans and individually from one operation to the next by hand. (*Courtesy Saginaw Steering Gear Div., General Motors Corp.*)

particularly to assembly of bulky parts in a subassembly close to main assembly lines.

**Odd-angle Arrangement.**—Some layouts bear no pattern at all but are merely the result of fitting machinery and equipment together to the end that work may be passed easily from one workplace to the next. This jumbled or odd-angle layout of equipment is especially applicable in fabricating small parts, as is the case shown in Fig. 45. Its chief disadvantage is that the machines and workplaces are inaccessible to maintenance men, stock handlers, supervisors, inspectors, and the workmen themselves. Frequently, in the change of such a line, it is necessary to disconnect or remove half a dozen machines in order to replace one. Obviously, no one conveyor can be used throughout the line. Moreover, the odd shape may not fit neatly into the rectangular arrangement of the building, aisles, or other lines.

By way of summary, the straight line is preferred unless:

Its length makes supervision difficult, the feeding of parts and subassemblies awkward, and the use of floor space wasteful;
Available space requires a more compact arrangement;
The return of empty fixtures is difficult;
Certain work stations are common to more than one line or more than one operation in the same line;
Connections have to be attached for more than one or two stations;
Small parts are more easily handled if regularity is ignored.

In such instances, the layout finally selected will be a compromise from the theoretical ideal.

**Flow in the Plant.**—In arrangement of the various lines to relate to the flow within the plant, the principle of maximum handling of stock in the rough state influences the layout. Wherever possible, the handling of finished parts should be lessened. This is important not only to minimize handling but to lessen the damage to material and the need for extreme care in transport. This principle favors the completion of parts and subassemblies close to the point of usage. If this is not feasible, parts can be finished along a given aisle, and the rough stock can be fed from the opposite end of the line or from another aisle. Figure 46 shows the correct and incorrect layouts. Lines may have irregular starting points, for rough stock can be handled readily and, in any event, there is usually a storage ahead of each line.

Figure 47 shows subassembly lines feeding or flowing to another line, aisle, or conveyor. In the first case, they are feeding toward the center. This again has an advantage over distributing the stock in the center and having it flow

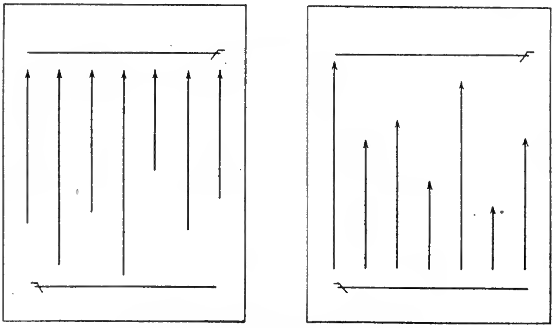


FIG. 46.—Flow within the plant.

outward, since the finished stock receives a minimum of handling. It also allows feeding lines to converge from both sides. When the outside lines or aisles are placed against the walls of the building, feeding from the center may be

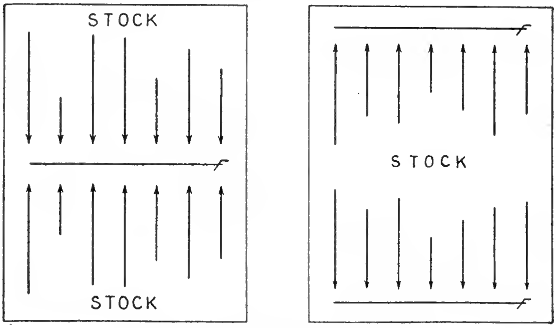



FIG. 47.—Flow within the plant.

satisfactory, for the larger central floor space may be used more economically. The main lines do not block the central area, and any tool or storage cribs can be centralized.

## LAYOUT ENGINEERING

Since the final layout of any line is the result of analysis of many different functions, the layout engineers are constantly in touch with the other groups in the plant responsible for getting the line set up and running. All should approve the layout before it is installed, and no detail should be overlooked. Figure 48 shows a check sheet used by the layout department of one metalworking concern to check its own layouts.

The place of the layout engineer in the organization is not fixed, and he may operate in a number of departments. In one company the layout engineer was made responsible to four separate groups within a period of a very few years. The following departments are typical of those where one is likely to find the layout engineer in an organization: plant engineering, process engineering, methods department, and plant superintendent or works manager.

It is generally recognized that good plant-layout engineering is essential to the best arrangement of the equipment and the proper setting up of the line. If frequent changes are to be made, as they are in most instances of line production, this work should not be relegated to a part-time engineer whose primary interest is elsewhere. Yet in many smaller plants or in those with sporadic lines, this work is combined with other work, such as processing, motion study, and line balance.

**Layout Techniques.**—The tools most commonly employed in layout include some form of process sheet and a layout board. Variations in the types and exact methods of using them exist in every concern.

For small lines, and particularly where the layout engineer has a voice in establishing the sequence of operations and in the selection of equipment, a detailed process-flow chart may profitably be used. As a tool for rearranging an existing line or job, this device is of particular value. All operations, transports, storages, and inspections are listed, described, and symbolized for ready recognition. They are then analyzed for possibilities of elimination, combination, rearrangement, simplification, and breakdown. The importance of subdividing operations will be further considered in the chapter on balance. A process-flow chart is usually accompanied

## LAYOUT CHECK SHEET

The following should be used when working on a layout and when checking over a layout prepared by someone else.

1. Raw materials:
   - *a* Warehoused where
   - *b* Enters to job—how and from where
   - *c* The package—size and type
   - *d* Storage ahead of line—how, where and quantity
   - *e* Handling to first operation—equipment and unit weight
2. Fabrication line-up:
   - *a* Sample part
   - *b* Part prints
   - *c* Planning sheet
   - *d* Layout of machines
   - *e* Handling equipment
   - *f* Equipment inventory
   - *g* New equipment required
   - *h* Equipment available
3. Scrap:
   - *a* Chutes
   - *b* Pans or small trucks
   - *c* Scrap gondolas
   - *d* Cams on presses
4. Purchased parts:
   - *a* Quantities used—per day and month
   - *b* Quantities received per shipment
   - *c* Type of shipping container and quantity
   - *d* Storage—where, how and quantity
   - *e* Storage at point of usage
5. Inspection:
   - *a* Where—bench
   - *b* Gauges required—gauge rack
   - *c* Sample board
6. Assembly:
   - *a* Sample part
   - *b* Part prints
   - *c* Planning sheet
   - *d* Layout of machines
   - *e* Handling equipment
   - *f* Equipment inventory
   - *g* Parts storage—where and how much
   - *h* Parts supplied—how and from where
7. Packing:
   - *a* Carton supply—quantity and how stored
   - *b* Carton fillers—quantity and how stored
   - *c* Sample carton fillers
   - *d* Carton make-up
   - *e* Packing—where, how and amount per carton
   - *f* Disposal of package—to where and how
8. Cost of job:
   - *a* Project detail
   - *b* Work schedule
   - *c* Supply purchase request
   - *d* Shop work request
9. New product layout summary

   When a new layout is prepared, the project detail typewritten and the planning sheets, sample parts, etc. completed, proceed to tabulate the following items on that particular job:

   1. Number and name of part
   2. The number of part numbers of like parts
   3. Total number of pieces required per day
   4. New equipment required—standard machines
   5. New equipment required—special machines
   6. New equipment required for processes (plating conveyors, ovens, etc.)
   7. Equipment released for other uses
   8. Obsolete equipment for sale
   9. Productive floor space required in sq. ft.
   10. Non-productive floor space required in sq. ft.
   11. Warehouse space required in sq. ft.
   12. Available floor space released in sq. ft.

Fig. 48.—This list is used as a check sheet to be sure all factors involved in the layout have been considered. (*Courtesy of L. F. Zahn.*)

by a process-flow diagram or print showing the location of the different operations. Where the layout engineer cannot change the operations, he may begin his work with an operations list or routing sheet supplied by the process engineers or time-study department. Figure 49 shows a planning sheet used by one layout group.

Layout board work is more important to line production than to the job-order shop, because layout in the former case is a recurring problem. The board itself is generally con-

LAYOUT PLANNING SHEET

PIECES PER DAY 250 PART NAME COVER BRACKET PART NO B-62981
ALLOWANCE 10 % 25 RAW MATERIAL Die cast Aluminum DEPT 17
TOTAL PCS./DAY 275
PIECES/RUN 1 day - 275 DATE Dec. 17, '43 PREPARED BY Stan SHEET 1 OF 1

| NO. | OPERATION DESCRIPTION | NO OF OPERTRS /MACH | WAGE RATE | PCS./HR FROM MACHINE | HOURS PER RUN | DOWN TIME SET UP | TOTAL HOURS PER RUN | EQUIPMENT | MACHINE NUMBER | NO MACH. REQ'D | BANK BEFORE OPER |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | |
| 1. | Turn O.D. | 1 | .95 | 13.7 | 20 | 2 | 22 | Monarch Lathe | Standard | 2 | 275 |
| | Face shoulder | | | | | | | | | | |
| | Burr, Gauge | | | | | | | | | | |
| | | | | | | | | | | | |
| 2 | Drill 5 holes | 1 | .95 | 27.5 | 10 | 1.5 | 11.5 | Avey Drill | D-418 | 1 | 100 |
| | on rim. | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

FIG. 49.—Layout planning sheet typical of that used by many companies with fabricating lines.

structed of heavy fiberboard in order that fastening devices may be easily applied. Cross-section paper, prints, or photostatic negatives of the plant floor area may be laid over the board. The boards are generally kept small so that they may be conveniently worked upon. The board used for the large floor area shown in Fig. 50 has detachable sections. The scale is generally ¼ or ⅛ in. to the foot, as anything smaller will not allow clear designation of the equipment.

The templates may be cut out of paper, light cardboard, photographic film, or masking tape. Chutes, benches, and cribs or storage areas may be also represented by templates, as are aisles, columns, elevators, and rest rooms, if not already marked on the board. With cross-section paper and templates to scale, no dimensions need to be shown on the board or even on the reproduced copy. Various color combinations may be used for the templates to represent the machines in any one line or the different types of equipment. String is sometimes employed to show the flow of material. Fastening devices

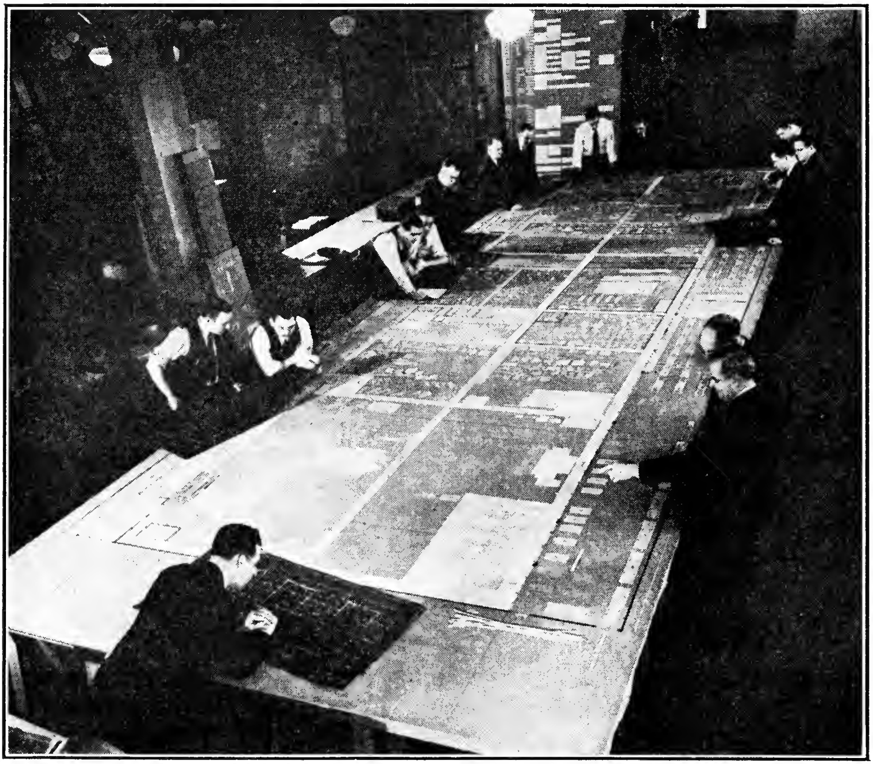


FIG. 50.—Layouts must be worked out in detail for every new line, large or small. This shows the layout planning of a tank arsenal similar to that in Fig. 5. Note three final lines at right. Board is divided for easy removal of any section. Templates are colored cardboard. (*Courtesy of Automotive Council for War Production.*)

include flat, colored map tacks, plain tacks, and staples. By these means, the proposed layout can be visualized and errors corrected before it is installed.

The work of layout customarily begins before the processing is completed, so that tentative plans for both may be carried on simultaneously. After the specific methods and man-power estimates have been determined, layout proceeds from the rough plan to the layout board. Trial lines are generally arranged in a straight line with corners or combinations put in later. As each person interested approves the layout, he generally initials the board. Copies may then be made for distribution. The fact that the layout engineer often has to persuade production supervisors to accept his arrangement is one that cannot be overlooked. This is more difficult than convincing the process engineer, for the production executive must be satisfied that he can make the line work as planned.

### EXECUTIVE READING

"Engines from the Ground Up," *American Machinist*, Vol. 84, p. 371. P. W. Brown and H. E. Linsley show plant use of U-shaped lines to avoid back-tracking of parts in production of aircraft cylinders.

"Plant Layout in Three Dimensions," *American Machinist*, Vol. 87, p. 87. W. A. Burton explains the use of scale models in aircraft assembly-line layout.

# CHAPTER VII

## BALANCE

The necessity of uninterrupted flow of material down the line needs no further explanation. It is equally apparent that evenness of production demands the equalization of operating times at the different work stations. This balancing of operations in the time allowed according to the desired rate of production is the main problem of line balance. Indeed, some plant managers believe that the layout of a line is only as good as its balance. This does not mean that all operations must be performed in the same time; it is necessary only that the interval for one worker's cycle of motions be a multiple of the cycle time set for the rate of production.

### OBJECTIVES OF BALANCE

In general, the purpose of balance is to permit, as far as possible, a thin, swift, and uniform stream of material to flow through the plant and, at the same time, to obtain *maximum utilization of man power*, *maximum machine usage*, and *minimum material or time in process*. If the product has a high labor cost, as in hand-assembly operations, the manufacturer will be primarily interested in the maximum utilization of his operators. On the other hand, in fabrication lines where there is a high machinery cost, he will be more concerned in keeping his machines fully busy. The objective of minimum work in process or minimum time in process is usually obtained in some degree by installing the operations in line form. However, the refinements of balance may allow even greater efficiencies in reduced inventories and manufacturing time.

Of course, 100 per cent balance is rarely attainable. There is always some extra machine capacity or surplus operator time in certain work stations of the line. Even with line production in one machine there may be one limiting operation which holds back the others.

**Assembly and Fabrication Line Balance.**—It is much easier to balance assembly lines than fabrication lines. In fabrication work, the machine itself largely determines how long the operation will take, except where tooling attachments or handling devices may be used to reduce the make-ready and the put-away. Thus the engineers who specify the methods and equipment will, in large measure, establish the degree to which these operations can be balanced.

In assembly operations, machine time seldom limits the flow. It is much easier to analyze hand operations, or those using portable tools, into elements and to distribute these elements along the line so that the labor time in each work space is equalized. Such operations may more readily be subdivided, combined, rearranged, or improved to keep operators fully busy.

## BANKS AND FLOATS

Storage areas in the line or intermediate quantities between operations are especially important to line balance. Small amounts of material are generally carried on all fabricating lines between operations as reservoirs to accommodate variations in the operating time of each machine. This is entirely apart from the storage of material for protection against delays in delivery to the line or equipment breakdowns in the line.

Many names have been applied to material in process which is in either permanent or temporary storage within the plant. The most common terms used in line production seem to be *bank* and *float*. A bank is any store of material. It is generally positioned at the head of the line, or at certain places along the line, to be drawn upon by operators when needed. The terms *dead bank* and *safety bank* indicate that the storage is reasonably permanent, that is, not to be used except in cases of emergency. A *live bank* is continually being built up from one side and reduced at the other. A live bank on the line is really part of the float. Banks are also referred to as buffer stock, cushion of material, material in the pause zone, or ripple in the line.

The term *float* applies to the amount of material in process which is moving through the line. It is generally used to indicate the number of pieces in the entire line, though it is applied to material in transit from one line to another or from the suppliers to the plant. When *float* is used in the larger sense, as including all the parts of a certain type in the factory, it will include safety banks as well. This is also called the *system*, or number of pieces in the system.

**Size and Location of Banks.**—The size of the part being fabricated limits the amount of float possible between operations. On small parts, 2 or 3 days' supply may be carried in float between machines and hardly noticed. Bulky items usually must be disposed of rapidly, and practically no parts can be held between one operation and the next. The storage space between machines is here an important factor. Some manufacturers purposely locate machines and work areas close together so that operators and foremen cannot build up the float. The modern fable of the manufacturer who piled the material so high it would fall on the workmen unless they hurried to perform their operations does not reflect current realities.

Sometimes no material is carried between operations or work areas. In other cases, the line is loaded with a large or heavy float. Ordinarily, it is desirable to operate the line in a close, tight, or "lean" condition and to carry only a few extra parts for protection. Where a breakdown or spoiled work is likely, where tool change is required, where the personal needs of the operator are not balanced, or where for any other cause interruptions are likely, it becomes desirable to make an allowance for delays and to plan the float to cover that period. In pressed-metal lines, hoppers between the various machines may hold most of the float. Again, automatic trips, catches, chutes, and the like are set up in a variety of ways to keep bins or storage piles filled with the normal float ahead of each operation. Where critical operations may hold up the line, a safety bank may be put into the line and held there in either a live or a dead form, as Fig. 51 shows.

In the arrangement of safety banks, the question arises whether material should be stored immediately beside the line or in an adjacent area. The arguments in favor of storing on the line are ready availability, less handling, and, in some

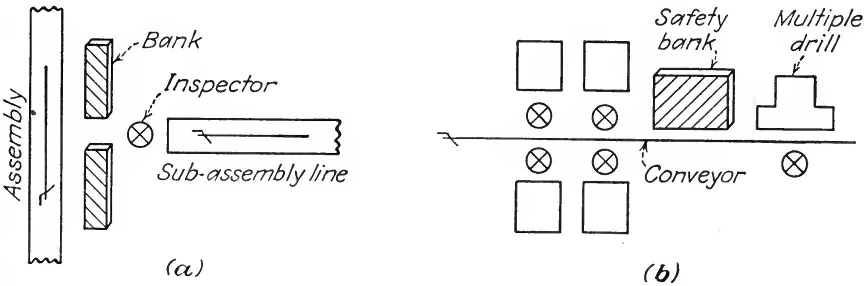



FIG. 51.—Banks of material are placed where they will afford protection. *a.* The bank is held between the inspection point and the assembly line so that a number of rejected subassemblies will not hold up the assembly line. Even without an inspection it would be desirable to keep a small bank for fear of subassembly conveyor shutdown (jam, blown fuse, etc.). *b.* The bank is placed after a critical multiple spindle machine which is likely to be out of adjustment frequently or for a relatively long period of time.

instances, greater convenience. On the other hand, if the parts are fragile or subject to pilferage, it may be wise to safeguard them in a separate storage area. There is also the psychological consideration. Where the bank in a separate area is drawn upon, the delay is certain to come to the attention of the foremen, maintenance men, or material handlers. This last argument is neutralized in those plants where the operators are required to report to their foremen as soon as any delay occurs.

Methods of holding the float or bank between operations include stock racks beside or on the line, shunt or spur conveyors, or special devices to hold the material. A large float will be automatically maintained whenever the parts are moved in lots rather than individually. Automotive crankshafts may be supported on a rack holding five shafts. When an operation on all five is completed, the rack is pushed along the conveyor. Branches of conveyors or spurs may be built beside the main line so that a bank can be maintained with a minimum of handling. Recirculating conveyors or turntables may be used, as Figs. 52 and 53 show.

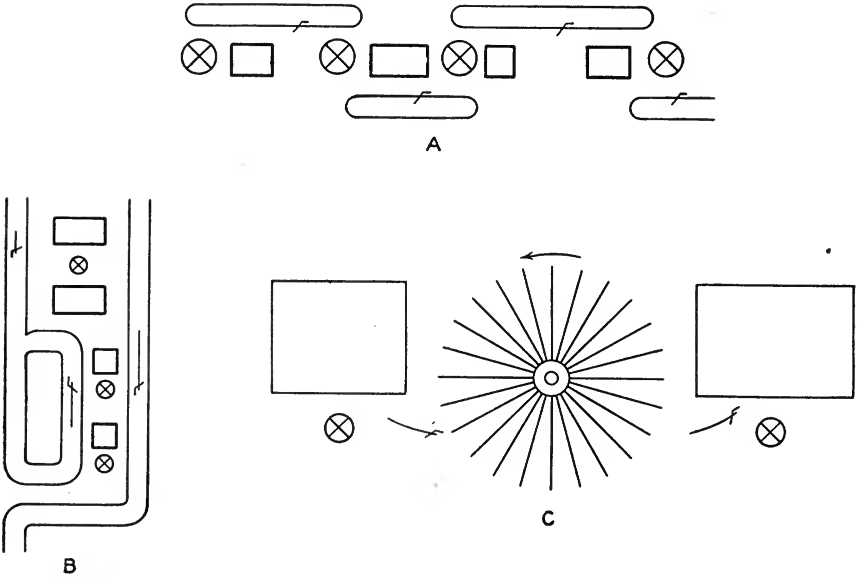



FIG. 52.—Recirculating conveyors for holding material between operations. B shows how a loop can be employed to accumulate parts ahead of machines operated intermittently. C represents a pronged type of conveyor used to allow drying time for rubber cement, the stock being draped over each prong.

**Bank-size Formulas.**—In order to eliminate the banking of material and, at the same time, to obtain smooth flow, it sometimes becomes necessary to reduce the speed of a fast machine or assign operators to nonproductive work. When it is possible to bank material, the fast machines or idle operators can sometimes be used on other work. This means that room to store material must be made on both sides of the rapid operation. The minimum bank size which must be built up to protect subsequent operations before the more rapid machine is switched to other work is equal to the rate of production times the length of time the machine is to be down. This is the same amount, of course, that will build up ahead of this machine while it is not operating as a part of the line.

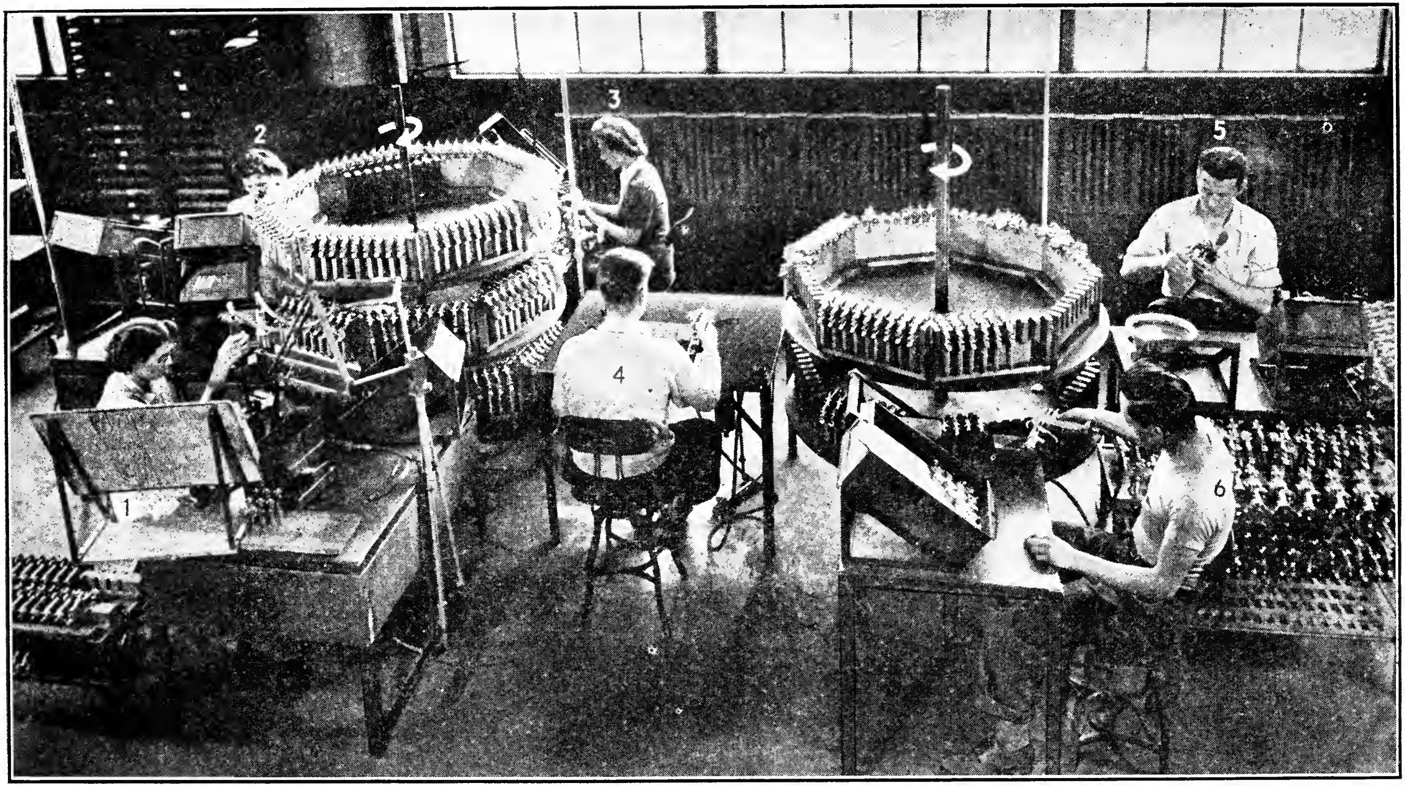



FIG. 53.—This six-station line for making paint spray-guns uses two merry-go-rounds. The bank between two particular operations is always held on the same shelf. This view shows a condition of unnecessarily large float. Operations are as follows: 1. Assemble fluid tip, needle, packing, and packing gland and plug. 2. Assemble air tube, handle, connect nut, adjust screw, and spring. 3. Assemble valve cage, valve packing, and trigger. 4. Tighten cage and horn adjustments and valve. 5–6. Assemble air cap and test. (*Courtesy of The DeVilbiss Company.*)

When this faster operation is being performed as a part of the line, the amount of bank that will accumulate is equal to the difference in output of the fast operation and the line, multiplied by the time allowed for the accumulation. This may be expressed by the simple formula

$$B = (C_m - C_l)T$$

where

$B$ = bank size.
$C_m$ = machine capacity, per hr.
$C_l$ = line capacity, per hr.
$T$ = period of time, hr.

If the high-speed equipment is at the end of the line, it can be started late and yet finish with the others. The time difference between the starting of the line and the speedier equipment may be found by the formula, $T = Q(1/C_l - 1/C_m)$, where $Q$ = the quantity to be produced in the run, cycle, or day and the other symbols are the same as above.

This last formula, with $C_l$ and $C_m$ interchanged, holds for the slower-than-line machine, when it is first in the line and must start ahead of time. For example, if the first operation produces 600 pieces per hour, but the line capacity is 800 pieces per hour and the quantity for the day is 4,800, the time at which the slower machine will have to be started ahead of the line equals $4{,}800(1/600 - 1/800) = 2$ hr.

**Line Speeds.**—The length and speed of the line are dependent on the rate of production desired. From this, the cycle time, or time required between pieces coming off the end of the line, can be easily found.

$$\text{Cycle time, min.} = \frac{60}{\text{hourly rate of production}}$$

This is the maximum time a piece should remain in any station unless there are duplicate stations. Where the stations are evenly spread along the line, the speed will bear the simple relationship:

$$\text{Speed of line} = \text{space per station} \times \text{rate of production} = \frac{\text{space per station}}{\text{cycle time}}$$

The space per station is dependent on the size of the unit, the room required by the workers, the space available in the plant, and the number of operations which have to be performed.

The length of the line also depends on this spacing.

$$\text{Length of line} = \text{space per station} \times \text{number of stations}$$

The length of time on the line, or line time, is as follows, excluding the idle time in banks between operations:

$$\text{Line time} = \text{sum of all operating times (including idle time to balance)} = \text{cycle time} \times \text{number of stations} = \frac{\text{length of line}}{\text{speed of line}}$$

Where subassembly or fabricating lines feed the final line, the rate of production will be the same for both, provided, of course, that there is only one of each subassembly in the final unit, and provided that both lines operate the same number of hours per day. While this means that the cycle time will be the same for both, the speeds may be entirely different, depending on the spacing of the pieces on the two lines.

For example, if a fabrication line directly feeds an assembly line, it is possible to determine the speed of the fabricating conveyor by knowing the production of the final line, the number of these particular parts used in the final unit, and the spacing between parts on the feeding line. If two fabricated pieces are used in each final unit and the spacing between these pieces is 4 ft., and three finished units are wanted per minute, it can readily be seen that three times two, or six, pieces are required per minute from the fabrication line. Six pieces per minute times 4 ft. per piece is a line speed of 24 ft. per min., a speed completely independent of the speed of the final line.

Frequently the speed of a line is left in the hands of the workers, though a minimum speed may be set.

## METHODS OF BALANCING

One method of obtaining balance, which at first glance seems logical, is to take the lowest common denominator of the output of each machine or operator and balance from this base. For example:

| Operation Number | Capacity of Machine, Units per Hour |
|---|---|
| 1 | 30 |
| 2 | 40 |
| 3 | 10 |

Lowest common denominator = 120

For balanced operation:

| Operation number | Output, units per hour | Machines needed |
|---|---|---|
| 1 | 120 | 4 |
| 2 | 120 | 3 |
| 3 | 120 | 12 |

The obvious difficulty with this procedure is that here the balance itself specifies how many units will be made per hour. Actually, this rate of production should have been previously established, depending upon other conditions. The line must be set up to meet the rate of flow; the output can seldom be controlled by the desire to obtain full machine utilization. Such a method would require considerable extra equipment and man power. Moreover, it is practically impossible to get a common denominator when there are many different operations with capacities that do not fall into round numbers.

In some cases where the times of all operations are nearly equal or are even multiples of a convenient cycle time, the line will be set at this rate, and the length of time at which the line operates will be adjusted to give the desired output.

**Banks.**—Perhaps the simplest method of balancing operations is to bank material and operate the slower machines overtime or on additional shifts. This is an easy procedure but rarely achieves the objectives of balance. It results in large amounts of work in process accumulating at the various constriction points, with corresponding increases in floor space and manufacturing time. It raises the problem of adequate supervision for the overtime work. There will be extra costs

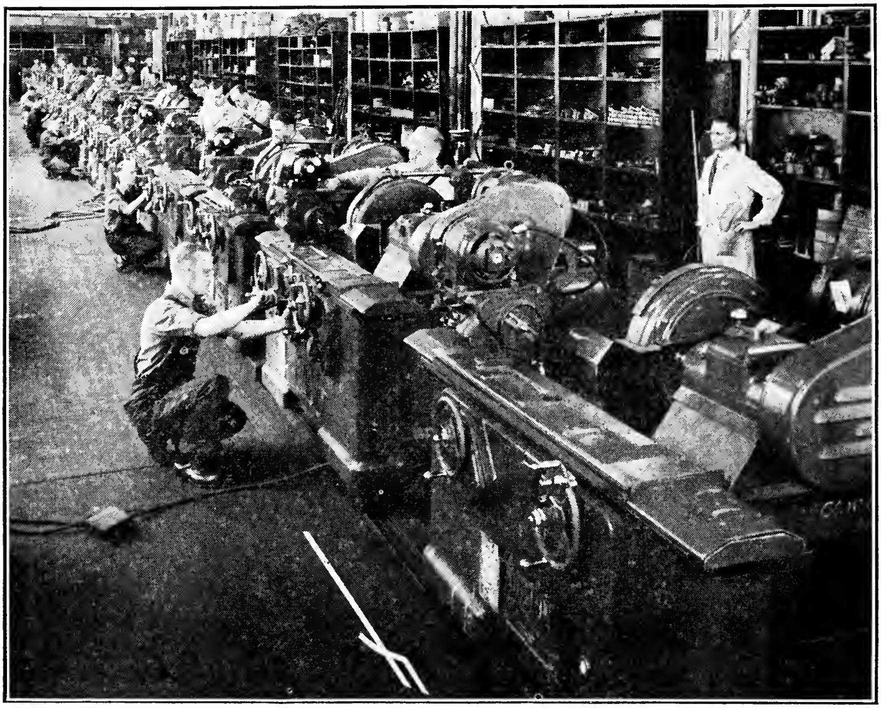


Fig. 54.—This grinding machine assembly line is well balanced at this end. The inability to standardize such operations as scraping-in of bearings makes for loose balance and a large float at the upper end of the line. Machines remain at this line close to 20 working days. Note guide rail and platform dolly for moving the machines. Note also the nearby stock racks. (*Courtesy of Norton Company.*)

of light and heat and probable interference with maintenance routines. Such a method is not possible where the plant is operating on a 24-hr. basis. A similar method, which is seldom practical, is to let a worker do as many pieces as possible and to send the surplus above line requirements to another operator who will complete the remaining operations on a lot basis. Most companies favor a more precise approach, usually attempting a theoretical balance before setting up the line.

Here the bank size allowed may be definitely specified in order to avoid such heavy accumulations in process. Figure 54 shows an assembly line with irregular movement, and a float of several days' production.

Moving material in lots is essentially the same as maintaining a bank. It allows variations in operating times to counteract each other, so that an average work interval may be used. Individual moves would mean that the longest possible time ever to occur on an operation would be allowed as the cycle time.

The reduction of machine speeds is seldom an economical device. It is far better, when the operator has extra time, to give him some odd job such as burring or gauging his work, performing certain subassembly operations, or doing miscellaneous bench work. Some plants go so far as to have production men sweep the plant when their idle balancing time cannot be used on any other job.

**Moving Operators.**—Moving the operators along the line to cover more than one operation is a common method of balance. When his operations are relatively fast, a worker can perform two or three tasks by moving from one station to another, sometimes even on different lines. If his operation is longer than the time allowed per station, some other worker may be assigned to help him part time.

Where the operation takes longer than the time allowed per station, workers may be assigned to every second or third piece, the operator moving along with the work through two or three stations. Figure 55 shows a case where a worker may ride the conveyor several stations. When he finishes his cycle, he returns to his original position on the line. This requires alternating operators, and sometimes there are alternating crews of several workmen each. This may be carried to the extent where one operator moves with the work along the entire line, a procedure which generally applies to special assembly work. For example, on one truck-assembly line, a special truck with extra front-end parts was scheduled every hour. One operator was assigned to attach all these special parts. He rode with the line nearly 200 ft., performing these tasks; when they were finished, he returned to the head of the line to undertake the next special job. In another instance, several workers moved up to the head of the line each day and operated the first two machines until enough parts were banked to last the rest of the line throughout the day. They then moved back to their work stations in the line.

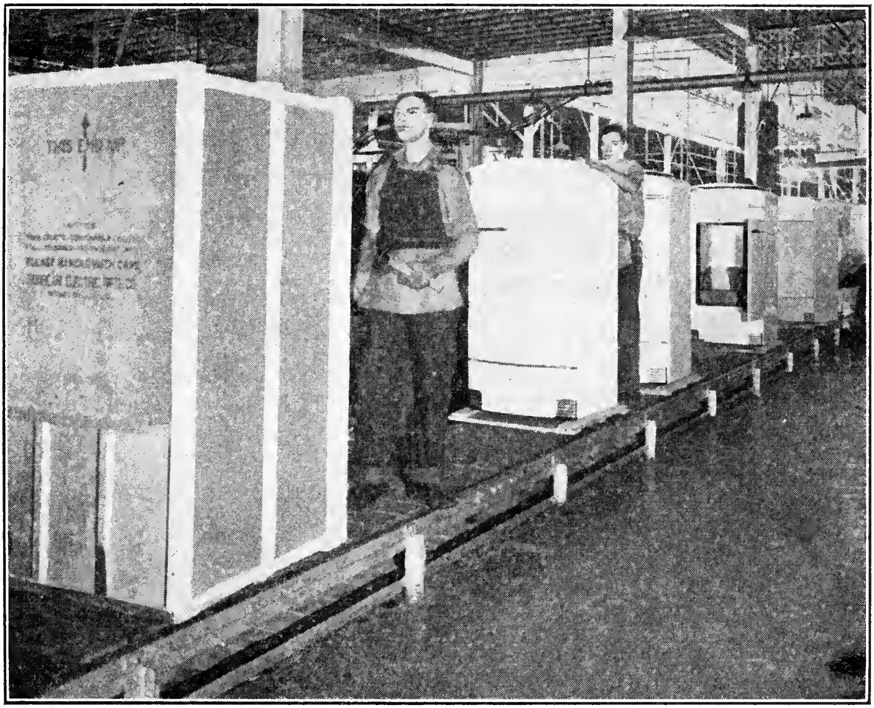


FIG. 55.—Crating operations on refrigerators are performed on the conveyor. A certain worker may be assigned several stations before returning to pick up his next refrigerator. (*Courtesy of Sunbeam Electric Manufacturing Company.*)

**Combining or Subdividing Operations.**—It is often easy to subdivide, combine, change the sequence of, or readjust otherwise operations or their elements to equalize operating times. This is commonplace in assembly work and merely means that each worker performs at his one workplace that portion of the complete job that time allows. Where it is possible to spread both the workmen and the operations along the line, a reasonably high degree of balance may be attained. Some manufacturers combine several operations and workmen so that a team of five workers is covering three operations. Sometimes the operation cannot be subdivided because of its nature. A particular skill may be required; there may be the necessity of fixing responsibility; or added expense may make such subdivision impractical.

**Improved Operations.**—In many cases, the equipment, tooling, or handling methods require alterations in order to balance the operation. Speeds of machines may vary, feeds may be increased or decreased, the stroke of the machine may be changed, jigs and fixtures may be redesigned, and handling devices improved on bottleneck operations to bring them up to line output. Even the plant layout may be changed to cut the nonproductive handling time at the bottleneck operation.

**Improving Operator Performance.**—Occasionally, balance may be obtained by using the fastest or most able workmen on the more complicated operations. Normally, time studies will pick out constriction points, and attempts can be made to eliminate them in the planning stage. Unless the worker receives a higher rate of pay, or unless there is an incentive-wage plan, it is difficult to accelerate slower operations by the use of operators working at better than average performance.

## BALANCE PROCEDURE

The chief prerequisites for balancing a line are:

The rate of production at which the line will be operated;
The necessary operations and any requirements as to sequence;
The time necessary to perform the various operations.

Previous chapters have dealt at length with the first two of these requirements. Operation times are preferably determined by time-study engineers. Time study has received its share of adverse criticism, but it is only with such objective time values that a line may be scientifically planned for balance. Here is a problem met by time study that is not encountered in the job-lot plant. When setting up a new line, records of this sort may not be available. In this instance,

FIG. 56.—Experiments in line balance are tested on this balance board which shows a long belt conveyor. Map tacks are used to represent operators, while colored thread indicates any grouping of operators in a crew or any path of travel they must follow.

operation times will have to be estimated from experience with similar work.

**Planning the Balance.**—The actual work of balancing generally begins with a listing of the operations or various elements. By consideration of the sequence necessary and the various methods of balancing, an attempt is made to group the operation elements so that the total time for each operator is equivalent to that allowed by the rate of production for one cycle. Operator charts, man-machine charts, and other tools of the motion- and time-study analyst may here be of assistance. Figure 56 shows a balance board on which the balancing of operators can be planned.

Whenever possible, this "paper balance" should be worked out before the line is installed and is best accomplished while the line layout is still in the planning stage. Actually, it seldom is finally established until the job is tested on the line.

After the balancing has been arranged, instructions are sent to the shop along with the other manufacturing data. These may take the form of routing sheets, instruction sheets, or layout drawings showing the positioning of operators. The work pattern or routine for workers to follow in their operation cycle is usually indicated; the foreman is shown how the work can be done with the personnel and time allowed him.

When the line is paced by a powered conveyor, there is little problem of informing operators of the time allowed them per cycle. In some instances, signals, such as a bell or siren, notify workers when the parts are to move. Clocks or indicators with rotating hands (as shown in Fig. 57), markings on conveyors or floor, or optical signals have been used with success, particularly in conjunction with an acoustical device or in places where they do not interfere with the worker's concentration. When the cycle time is long, warning signals may also be used.

**Adjusting the Balance in the Shop.**—In actual practice, much of the positioning of personnel along the line for best balance is arranged by the foremen. Delays and changes in production schedules make it advisable for foremen to move their men around in order to keep them busy. Frequently, the workmen enjoy the opportunity to vary the balancing slightly from that outlined by the production engineer. Where there is a group-bonus wage-incentive system, minor details of balance are sometimes left entirely to the operators themselves.

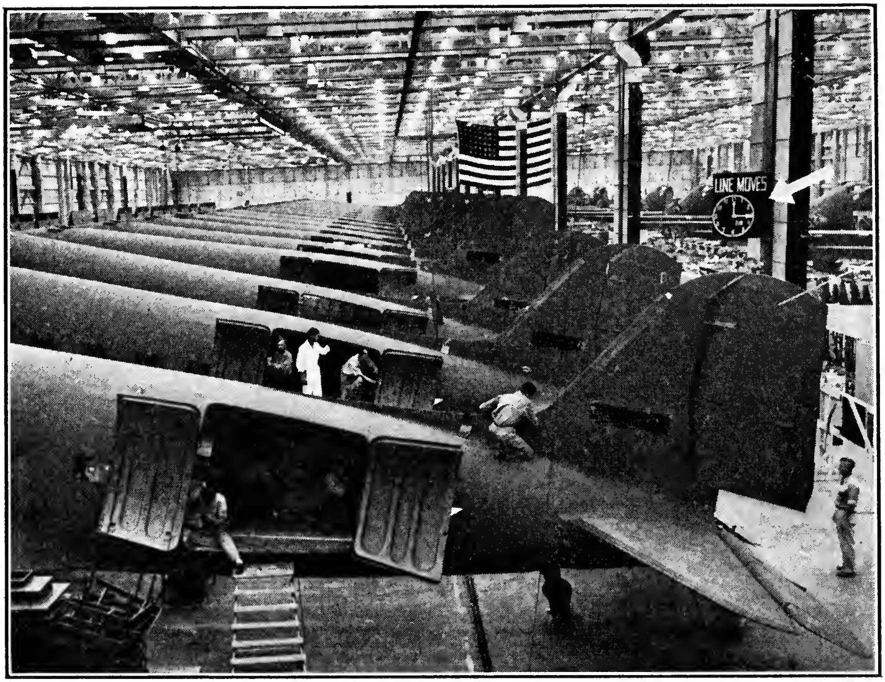



Fig. 57.—The hands on the clock face are set to indicate when the line will next move. Here is intermittent movement and a long cycle time. (*Courtesy of Douglas Aircraft Company, Inc.*)

One common procedure is to determine operation-time standards, to assign the number of employees required for the line, and to work out some degree of planned balance. The responsibility for getting out the work in the time allowed is then placed on the foreman. Guided by the balance instructions, the foreman locates the operators according to their labor classifications and the time standards as set. Frequently, he can improve upon the time allowed, particularly if this is used as a measure of his operating efficiency.

Conversely, if he and his workers cannot meet the rate set, a restudy of the operations and the line balance may be requested. Yet, as long as he maintains the rate of production with the allotted personnel, there is no interference in his method of balancing the line. This practice generally means that foremen will build up unduly large banks, and it cannot be recommended as a precise method of organizing line operation.

Although a tight balance to which the workmen must strictly adhere is not always practical, the problem of improvement in balance should not be left entirely to the discretion of the shop. Assistance by some group other than production will be needed. Nor should the problem be "the responsibility of everyone in the plant." At one job-lot plant, a bottleneck between the production and inspection stations resulted in the accumulation of nearly 2 months' supply of material before the constriction was removed. Such situations can be easily noted in line production and are automatically avoided when proper balance has been introduced.

## MECHANICS OF BALANCING

Techniques of balancing vary widely, each manufacturer developing some system to fit his particular needs. Therefore, a few specific cases will illustrate how balance may be obtained under different conditions.

**Assembly-line Balance by Grouping Operation Elements.**—A producer of electrical instruments uses the following method to balance assembly operations. The desired rate of production on a certain instrument is 2,400 per week. The engineering department lines up the list of assembly operations. The methods men then make up, for each operation, left- and right-hand operator charts showing the chronological movement of each hand and the standard or estimated time (with allowances) for each element or portion of the operation. The sum of the elemental times gives the total time for each operation. The data then are as follows:

| Operation Number | Time, Seconds |
|---|---|
| 1 | 114 |
| 2 | 73 |
| 3 | 34 |
| 4 | 48 |
| 5 | 62 |
| 6 | 20 |
| | Total 351 |

The methods engineer then computes the cycle time:

Desired rate of production = 2,400 units per week

With a 40-hr. week and one shift, this is 60 units per hour or one unit every 60 sec. Thus 60 sec. is the cycle time.

Next the methods engineer divides the operating time required to produce a complete unit by the cycle time:

$$\frac{351}{60} = 5\frac{51}{60}$$

This shows that six operators are needed, the sixth one working only 51 sec. of the cycle time. Usually, the first operator in the line is given the 51-sec. job. This is done so that the conveyor will always be full, for if any delay should occur in the first operation, it can be absorbed more readily there than in the rest of the line. So the first operator, if she cannot be assigned to other work, is allowed a little safety margin of idle balancing time.

The methods engineer than takes the left- and right-hand chart for the first operation and notes that the time is 114 sec. He runs down the time scale to the 51-sec. point and draws a line. All elements of the operation above this line constitute Operation 1. He moves down the time scale 60 sec., and draws another line. The elements between these two lines represent new Operation 2. He keeps on drawing lines for each 60-sec. interval all through the left- and right-hand charts until he reaches the end. He then has a series of new operations, often combinations of two or three of the old operations, arranged in the proper sequence. This method can be visualized by the accompanying diagram (Fig. 58).

Each operator is given a sheet describing her operation in detail with the approved motions set up by the methods department. After the line is running, a methods engineer restudies all the new operations. If he finds that some are more difficult than others, he will make minor adjustments,

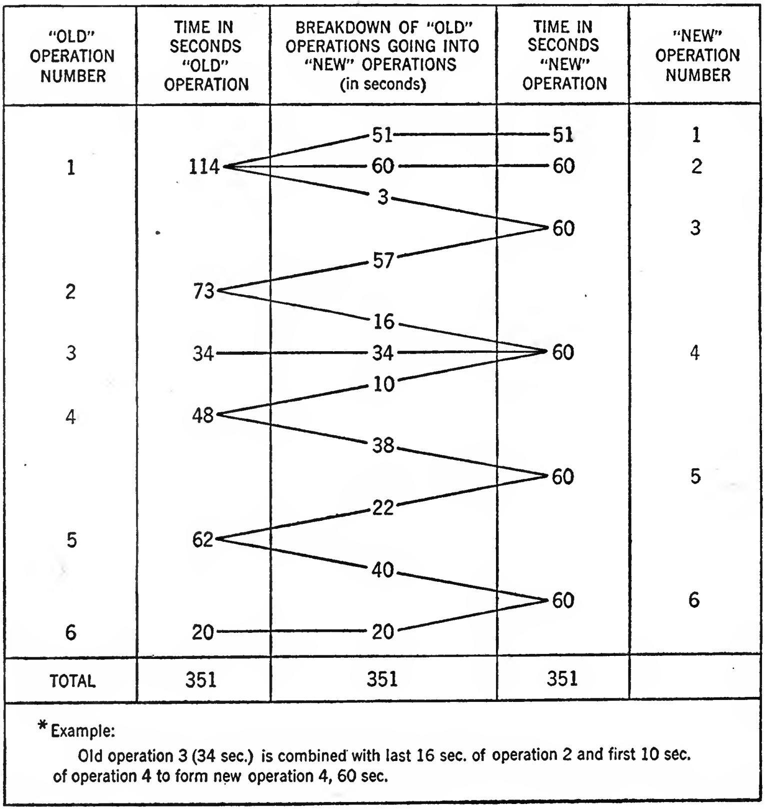



Fig. 58.

removing a small element from one operation and adding it to another, until the line is working in perfect rhythm.

This rather simple method of balancing is, of course, not applicable unless individual operations can be split up at almost any desired point into a grouping of elements.

**Simple Balance by Shifting Operators.**—A shoe company, in setting up production lines, uses the following means of balancing work assignments. In the line-up illustrated, there are nine operations, all time-studied. From this information, a chart is drawn similar to that in Fig. 59. Here the first column lists the operation numbers; the second, the standard times in man-minutes per pair. The third column indicates the theoretical number of employees or fraction thereof neces-

| Operation number | Standard time man-min. per pair | Number of employees | Employees 1 | 2 | 3–4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.07 | 0.14 | 0.14 | .... | .... | .... | .... | .... |
| 2 | 0.73 | 1.46 | .... | 1.00 | .... | .... | .... | 0.46 |
| 3 | 1.05 | 2.10 | .... | .... | 2.00 | 0.10 | .... | .... |
| 4 | 0.15 | 0.30 | .... | .... | .... | 0.30 | .... | .... |
| 5 | 0.25 | 0.50 | .... | .... | .... | .... | .... | 0.50 |
| 6 | 0.32 | 0.64 | 0.64 | .... | .... | .... | .... | .... |
| 7 | 0.08 | 0.16 | 0.16 | .... | .... | .... | .... | .... |
| *8 | 0.48 | 0.96 | .... | .... | .... | .... | 0.96 | .... |
| 9 | 0.29 | 0.58 | .... | .... | .... | 0.58 | .... | .... |
| Total needed (theoretical) | | 6.84 | 0.94 | 1.00 | 2.00 | 0.98 | 0.96 | 0.96 |
| Total actually used | | 7 | 1 | 1 | 2 | 1 | 1 | 1 |

* Example: 0.48 man-min./pair × 2 pairs/min. = 0.96 men
Rate of production = 960 pairs/8 hr. day = 120 pairs/hr. or 2 pairs/min.

FIG. 59.

sary for each operation in order to meet the desired rate of output. This figure is arrived at as follows:

Production rate = 960 pairs per 8-hr. day
= 120 pairs per hour or 2 pairs per min.
Number of employees = man-minutes per pair × number of pairs per min.

As the total in the third column shows that 6.84 workers are required, seven must be employed. The chart is extended and a vertical column made for each operator. In each operator's column is listed the portion of his working time he is to spend on each operation. For example, operator No. 1 will spend 0.14 man-minutes, or 14 per cent of his working time, on Operation 1, completing it. He will also spend 64 per cent and 16 per cent of his time respectively on Operations 6 and 7, completing them both. These three operations account for 94 per cent of his time. Since Operation 3 cannot be split up, two or more workers must be assigned to this work. This is accomplished by having operator No. 5 spend 10 per cent of his time helping operators No. 3 and No. 4 on Operation 3. He spends 30 per cent of his time doing Operation 4, and 58 per cent of his time doing Operation 9.

This form of balance can be readily used where operators move quickly from one work station to another. In the above case, banks are actually used, and each operator receives a sheet directing him to spend a definite amount of time or produce a certain number of pairs of shoes at his first station before moving to the next workplace, a definite amount of time or pairs at his second station, etc. In this way the lost time due to moving from one work area to another is reduced.

The chief weakness in this system is that it depends upon the versatility of the workers. In order to move from one operation to another, the employees must have developed ability in these different directions. The workers may have to be convinced that they are not working harder than before and that they are not really going to have to do two or three jobs instead of one. Moreover, since this method of balancing disregards the sequence of operations, it is limited to use where the layout allows workmen to move about easily or where the sequence is unimportant.

**Rebalancing by a Graphical Method.**—This method is employed by the standards department of an automotive concern making aircraft wing sections on a powered conveyor line. The example shown is actually the rebalancing of the line to meet an increase in production.

Time studies or estimates give the times for all the operations to be performed in constructing the wing. The time-study analysis sheets show the elemental times, and from these, operation assignments are made by trying to match, or group, elements in such a way as to distribute work evenly.

Bar graphs, as shown in Fig. 60, representing time are plotted for these operations. This balancing graph indicates the number of workers for each operation, the time required

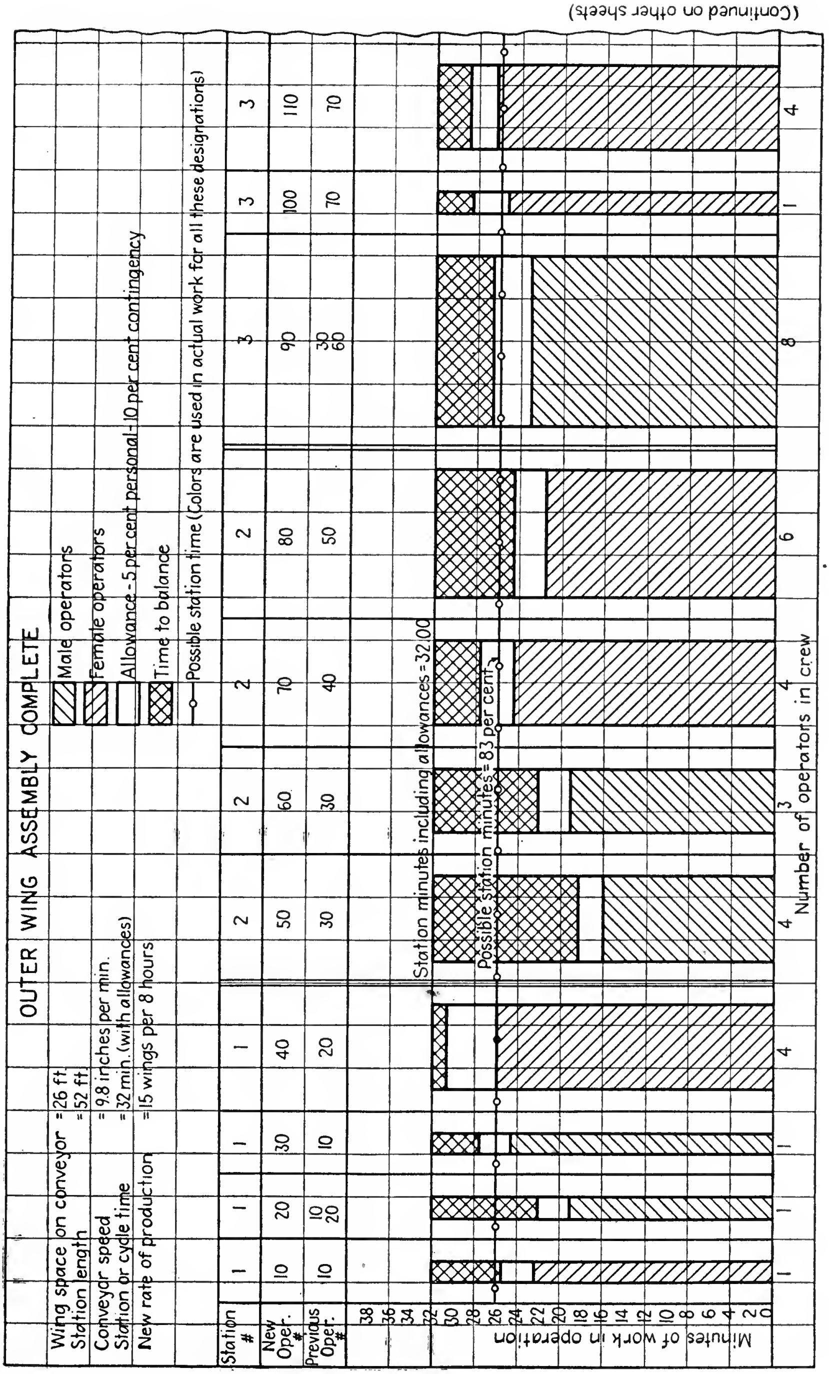

OUTER WING ASSEMBLY COMPLETE
Wing space on conveyor = 26 ft.
Station length = 52 ft.
Conveyor speed = 9.8 inches per min.
Station or cycle time = 32 min. (with allowances)
New rate of production = 15 wings per 8 hours
Male operators
Female operators
Allowance - 5 per cent personal - 10 per cent contingency
Time to balance
Possible station time (Colors are used in actual work for all these designations)
Station #
New Oper. #
Previous Oper. #
Station minutes including allowances = 32.00
Possible station minutes = 83 per cent
Minutes of work in operation
Number of operators in crew
(Continued on other sheets)

FIG. 60.

for each operation, the operations performed in each station, and the amount of idle balancing time. When the best attainable balance has been determined, an instruction sheet is made up, based on this chart, which shows what elements are included in each operation and presents the foreman with instructions on how to arrange his men along the line.

In this wing line, the change in output called for means that the speed of the conveyor and therefore the time in each station must be changed. A line representing the station or cycle time is marked on the chart, and each operation (including allowances) is composed of elements that will approach this maximum as closely as possible. The term *station time* is here preferred to *cycle time*, for sometimes (not in this illustration) there are alternating crews of workmen covering two or more stations in their cycle of operations.

A line marked "possible station minutes" is used to show how well the balancing is done. It represents the station time if all the idle balancing time could be eliminated—if it were possible to get 100 per cent balance. Actually,

$$\text{Possible station minutes} = \frac{\text{total man-hours to produce a complete unit}}{\text{station time} \times \text{number of men in the line}}$$

In the case of Operation 50, which is performed by four employees, there is a great deal of idle balancing time. This is necessary, because at this point the operators have to work in teams of two each, and the division of the work into elements cannot be improved. It was difficult on this job to spread green workers along the line to do other operations; operators moving between stations cause confusion, interference, and often delays in completing their primary operations. Management desired to have each operator in his own station (space marked on floor) at all times and to be able to fix the responsibility for a definite job on a certain number of workers and a certain area in the line. In some plants, this large idle balancing time has been reduced not by assigning workers to fixed stations of equal size, but rather by allowing them varying spaces along the line in which to complete each operation. This is illustrated in Fig. 61. Balancing here becomes a matter of apportioning floor space and being sure that workers do not interfere with each other.

**Balancing to Meet Line Standard.**—This example makes use of the line-standard, or line-task, idea. The line standard

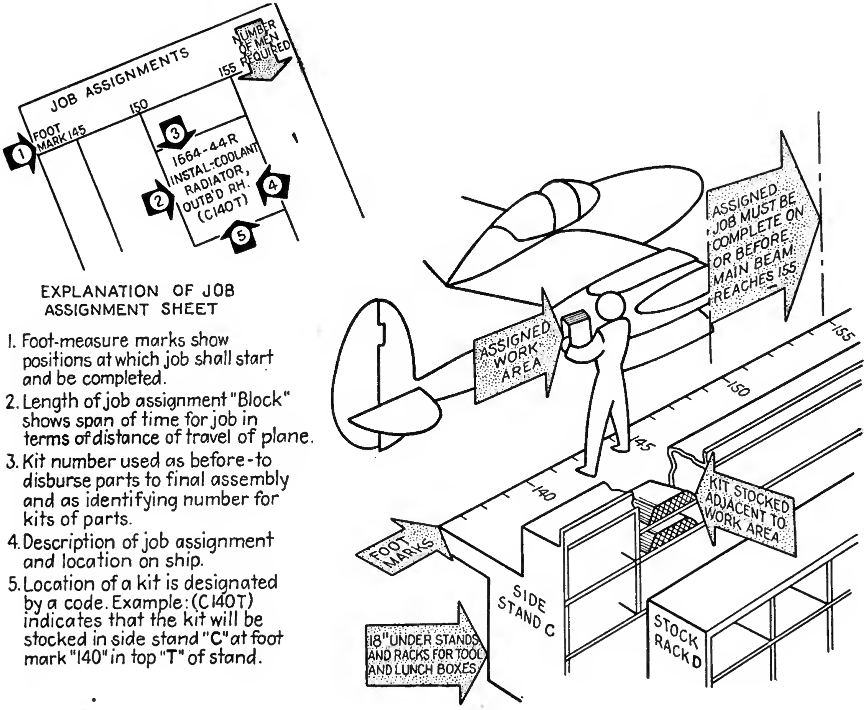



FIG. 61.—Balance has been worked out on a basis of so many ft. marked off along the line, rather than for spacing of equal stations. Group leaders are furnished job assignment sheets giving footmarks for beginning and completion of specific job, telling number of workers required, and giving location of stocked "kits of parts" needed for job. (*Courtesy of Lockheed Aircraft Corporation and Aviation.*)

is largely determined by the rate of production that is desired —actually being the pieces per hour that will meet the output called for, the number required every hour at each station.

The work of building the balanced operations begins with the determination of the time allowed for each portion of an operation. The time-study engineer will first list each operation or portion of an operation on a worksheet, and beside it the time allowed. He then begins to combine operations or portions of them in a way that will bring them up to the cycle time. When a balance has been roughly worked out, a line-standard form is filled out in pencil. This shows the degree to which the line is in balance and the information necessary to set up a balanced line in the shop. After approval, these sheets are typed and distributed to the foremen.

On the sample form shown (Fig. 62), the headings may be explained as follows:

*Class Rate.*—The hourly rate of pay of the workman to be used.

*Select Time.*—The actual minutes allowed per piece as shown on time-study observation sheet.

*Standard Time.*—The select time plus personal and fatigue allowances.

*Actual Standard.*—Number of pieces per hour at the standard time allowed; number of pieces made by an operator if working a full hour at the individual operation.

*Line Standard.*—The line standard, or task, that is set for the whole line as based on the slowest operation that will still allow the desired output. It will appear the same for all operations.

*Work.*—The standard time multiplied by the line standard. It shows the minutes of working time at the standard time rate to meet the line standard.

*Under.*—The amount of excess time of the operator, the idle balancing time. No figure should ever appear in the "Over" column when the line has been balanced, for otherwise the rate of production will not be met.

*Number of Changes and Time Allowed per Change.*—The number of moves made per hour by the operator, and the time used in moving, when operators cover split or part-time operations.

*Money per Operation per Hour.*—The theoretical money earned by the line workers, that is, the class rate times the working time of the operator allotted to the operation.

*Price per 100.*—Cost of the operation, that is, the money per operation divided by the line standard.

The column Combination of Operation indicates the analysis of the time the various operators will spend on each operation when these operations are combined. In the case shown, one girl operator is spread over Operations 60 and 80.

PART NO. 7768 PART NAME Instrument Case DEPT. 92 LINE STANDARD 22.4 - 1/2 M & 7G DATE 3-27-43 SHEET 2 OF 2

| OPER. NO. | OPERATION NAME | CLASS RATE | SELECT TIME (mins) | STANDARD TIME (mins) | ACTUAL STANDARD (pcs/hr) | LINE STANDARD (pcs/hr) | MINUTES PER HOUR: WORK | COMBINATION OF OPERATION | % OF TIME WORKING | OVER | UNDER | CAPACITY OF BANK | NUMBER OF CHANGES PER HOUR | TIME ALLOWED PER CHANGE | MONEY PER OPERATION PER HOUR | PRICE PER 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | Centralize part with tapered plug in .2187 diameter hole-clamp and bore .2187 diameter hole. Hand tap 1/4-32 thread. | 1.19 | 1.1607 | 1.3345 | 22.4* ½M | 22.4 ½M | 30.00 | | 100% | - | - | 60 | None | None | .5958 | 2.66 |
| 60 | Drill nine #33 -.1130 dimension holes eight thru and one 3/8" deep. Countersink same. Wash in can and blow off. Gauge 8 holes 75% and one 100%. | .89 | 1.7459 | 2.0078 | 29.8 1G | 22.4 PG | 44.98 | 1G 60.00 Available 53.78 Work 6.22 Excess 6.21 Changing .01 Idle Time | 100% | - | .01 | 1 | 23 | 3.105 | .6698 | 2.99 |
| 70 | Tap eight #33 holes .135-40 and one #33 hole .138-40 gauge 50%. | .89 | 2.2954 | 2.6397 | 22.7 1G | 22.4 1G | 59.13 | | 99% | - | 87 | 1 | None | None | .8803 | 3.93 |
| 80 | Blow out all the eighteen tapped holes with air. | .89 | .3415 | .3928 | 152 1G | 22.4 PG | 8.80 | | - | - | - | 1 | 23 | 3.105 | .1313 | .586 |
| 85 | Inspect and gauge all eighteen tapped holes at fabrication point. | .89 | 4.3490 | 5.0014 | 11.9 1G | 22.4 2G | 112.03 | | 94% | - | 7.97 | 60 | None | None | 1.6755 | 7.48 |
| | | | | | | | 405.64 | | | | 38.15 | | | 6.21 | 6.1949 | 27.656 |
| | | | | | | | | | $6.825 | (hourly rate) | | | | | | |
| | | | | | | | | | -6.1949 | (money earned) | | | | | | |
| | 7G @ .89 = 6.230 | | | | | | | | .6301 | (idle cost) | | ÷ 22.4 | (line standard)=added cost of | | | 2.813 |
| | ½M @ 1.19 = .595 | | | | | | | | | | | | | | | 30.469 |
| | 7½ Opers. = 6.825 Hourly Rate | | | | | | | | | Time Study Man: | | | V. Lake | | | |
| | | | | | | | | | | Production Engineer: | | | R. Douglas | | | |
| | $30.469 (price per 100 pieces) x 22.4 Line Std. = $6.82506 | | | | | | | | | General Foreman: | | | L. Smith | | | |

The accompanying symbols are used in balancing the operators: * = Controlling or Bottleneck Operation M=Man Operation G=Girl Operation PG=Part Girl, etc.

FIG. 62.

This is indicated by the drawn-in line. She could do 29.8 pieces per hour at Operation 60 and 152 pieces per hour in Operation 80 by working full time. But to meet the line standard, she need work only 44.98 min. and 8.80 min., respectively, at these operations. The sum of 44.98 and 8.80 is 53.78 min.; thus she can cover both operations in the 60 min. per hour. This leaves 6.22 min. for changing from one station to the other. If a bank of only one piece is allowed to build up, she will have to change with every piece, or 23 times per hour. This change time is charged against both operations equally.

Sometimes a team of six or eight operators may be spread in this way over a combination of four or five operations with considerable saving in idle balancing time. Such combinations can be made only where operators are allowed to move from one workspace to another.

**Balance with Particular Consideration for Machine Utilization.**—Still another company indicates details of its balancing on production routing sheets. These are developed from operations lists. The time-standards group checks the figures of the process engineers, assigns the time values for all labor, and establishes the man-power placement. In doing this, they work out the balancing of operations and the loading of machines. They are also charged with making all time-study observations and setting the labor cost for each job. They issue the routing sheets.

On the routing sheet itself (Fig. 63) is an operational coding for labor. There are three classes—*a*, *b*, and *c*. These refer to the experience and skill needed for the particular operation, because of the machine, tools, or instruments which have to be used; they have nothing to do with the job classifications of the workers assigned to the job. The term *group* refers to the group or section of the particular line or department. The *standard time per piece* includes an allowance for fatigue and personal needs, plus an established time for teardown and setup according to the number of pieces run per setup. This is the man-hours allowed per operation and may cover the time of more than one operator. P shows that the setup is permanent. Where the setup is not permanent, the allowed time for setup is given. The symbol S merely indicates that the job has been time-studied. *Balance* gives information on how to perform the operations for a satisfac-

**PRODUCTION ROUTING**

PART NAME Crankshaft PART NO. 194243

DATE 4-12-43 ISSUE NO. 4 NO. OF SHEETS 12 SHEET NO. 1

| OPERATION | OPER. NO. | DEPT. | GROUP | STANDARD TIME PER PC. | BALANCE | SET UP | HOURLY PRODUCTION |
|---|---|---|---|---|---|---|---|
| Receive | | 5 | | | | | |
| Inspect | | 59 | | | | | |
| Stock | | 21 | | | | | |
| Grind spot #3 main bearings | 10 b | 3 | A1 | S .0983 | | P | 11 |
| (Norton Grinder- #1037) | | | | | | | |
| Rough turn #1-4 & 7 main bearings | 20 a | " | " | S .2635 | Run with | P | 3.8 |
| (Wickes Lathe #2329) | | | | | oper. 30 | | |
| | | | | | ML .2635 | | |
| | | | | | MML .2325 | | |
| Rough turn #2-3-5 & 6 main bearings | 30 a | " | " | S (no | Run with | P | 3.8 |
| (Wickes Lathe #2377) | | | | time) | oper. 20 | | |
| | | | | | ML .2635 | | |
| | | | | | MML .2380 | | |
| Rough straddle mill c'weights | 40 b | " | " | S .1367 | | P | 7.3 |
| (Sunstrand Mill #2444) | | | | | | | |
| Rough mill 2-1/16 radii all arms but | 50 b | " | " | S .2860 | | P | Average |
| #6 & 7 (Cinn. Hi-Power Mill #2433) | | | | | | | of 3.5 |
| Rough drill holes in crankpins & ream | 60 b | " | " | S .6460 | MML .3230 | P | 3.1 |
| #1 pin | | | | | 2M-1M | | |
| (Footburt 2-Way Drill Press #2366) | | | | | | | |
| Rough face c'weight to 5" radius shoulder | 70 a | " | " | S .3148 | MML .1574 | P | 6.4 |
| (Melling Lathe #2328) | | | | | 2M-1M | | |
| Rough turn pins & face cheeks | 80 a | " | " | S .3822 | MML .1911 | P | 5.2 |
| (Melling Lathe #3107) | | | | | 2M-1M | | |

FIG. 63.

tory machine loading and balancing of operations. The coding symbols used are as follows:

$ML$ = machine load (time machine is being used).

$MML$ = maximum machine load (time to make piece if machine is utilized to fullest capacity).

$2M - 1M$ = two men running one machine, etc.

The sample sheet indicates that Operations 20 and 30 are run by one workman alternating between the two machines. Neither machine is operating at its maximum capacity, for there is some time allowed for the workman to move. On

Operations 60, 70, and 80, two workmen are allowed for each machine. The time allowed on the job is just twice the time in which the machine can perform the operation.

## EXECUTIVE READING

"Plant Layout for Aircraft Mass Production," *The Iron Age*, Vol. 151, No. 22, p. 52. C. Harper Brubaker describes the use of process-flow charts to assure the right amount of time and space for manufacture and for sub-assembly banks to feed overhead conveyor lines.

"Lay-outs for Mass Production," *Engineer*, Vol. 155, p. 530. H. R. M. Thorp instructs briefly on the actual mechanics of setting up a balanced production line in this British magazine.

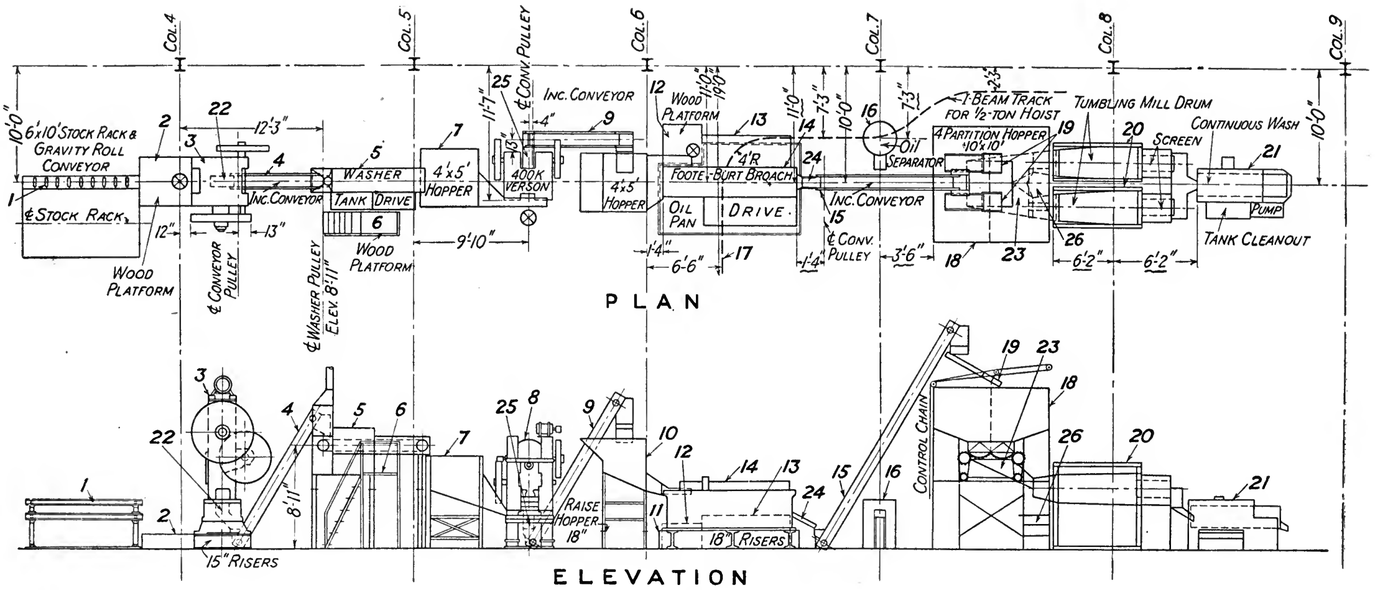
# CHAPTER VIII

## INSTALLATION

It is customary, in the early stages of planning the line, for management to request an estimate of the cost of the new setup. This may or may not act as a basis for an appropriation to cover the cost of installation. It is more likely that the request for funds will be made after the layout has been worked out in detail. A savings sheet can be prepared to show comparisons of any two or three installations in the event that the new line is merely a rearrangement of the present setup, or that there are alternative methods of lining up a new job.

**Installing the Line.**—After the funds have been appropriated and the proposed layout properly approved, the layout engineer and the supervisor of plant engineering or maintenance plan the actual installation work. The layout engineer supplies the details of how the rearrangement will be made. To do this, he may go so far as to draw up elevation sheets similar to that of Fig. 64, as well as floor plans. Such drawings locate the various parts of the production line, often including conveyors, nonproductive equipment, banks, and workmen. In rearrangement work on a small scale, the original layout plans can be used and the changes merely indicated on the drawing. For example, the addition can be shown in yellow on the blueprint with the old section blacked out. The revised print shown in Fig. 65 was used to relocate a conveyor.

In the event that any changes not contemplated in the original approval or appropriation are found necessary during rearrangement, these must be agreed to by the various parties interested. Such changes can generally be made without further request for funds if they do not bring the cost above the amount of the original authorization. In planning a line,




| DETAIL | NAME | EQUIP. NO. | REMARKS | DWG. NO. |
|---|---|---|---|---|
| 1 | STOCK RACK AND GRAVITY ROLL CONV. | | RELOCATE FROM DEPT. 17 TO 53 | |
| 2 | WOOD PLATFORM | | NEW | I-C2 |
| 3 | 510R NIAGARA | 5536 | RELOCATE FROM DEPT. 17 TO 53 | |
| 4 | INC. WIRE MESH BELT CONV. | | NEW | I-C4 |
| 5 | WASHER | 5763 | RELOCATE FROM DEPT. 17 TO 53 | |
| 6 | WOOD PLATFORM | | NEW | I-C6 |
| 7 | HOPPER | | NEW | I-C7 |
| 8 | 400K VERSON | | NEW | |
| 9 | INC. WIRE MESH BELT CONV. | | NEW | I-C9 |
| 10 | HOPPER | | RELOCATE FROM DEPT. 17 TO 53 | |
| 11 | OIL PAN | | NEW | I-C11 |
| 12 | WOOD PLATFORM | | NEW | I-C12 |
| 13 | WOOD PLATFORM | | NEW | I-C13 |
| 14 | FOOTE-BURT BROACH | 5553 | RELOCATE FROM DEPT. 17 TO 53 | |
| 15 | INC. WIRE MESH BELT CONV. | | NEW | I-C15 |
| 16 | OIL SEPARATOR | 1196 | RELOCATE FROM DEPT. 17 TO 53 | |
| 17 | I-BEAM TRACK FOR ½ TON HOIST | | NEW | |
| 18 | 4 PARTITION HOPPER | | NEW | I-C18 |
| 19 | (2) CHUTES (2)-2 WAY CHUTES | | NEW | I-C19 |
| 20 | TUMBLING MILL | | NEW | |
| 21 | CONTINUOUS WASHER | | NEW | |
| 22 | CHUTE | | NEW | I-C22 |
| 23 | LOAD CHUTE | | NEW | I-C23 |
| 24 | CHUTE | | NEW | I-C24 |
| 25 | CHUTE | | NEW | I-C25 |
| 26 | WOOD PLATFORM | | NEW | I-C26 |

FIG. 64.—Elevation drawing which will greatly simplify the actual work of installing this line.

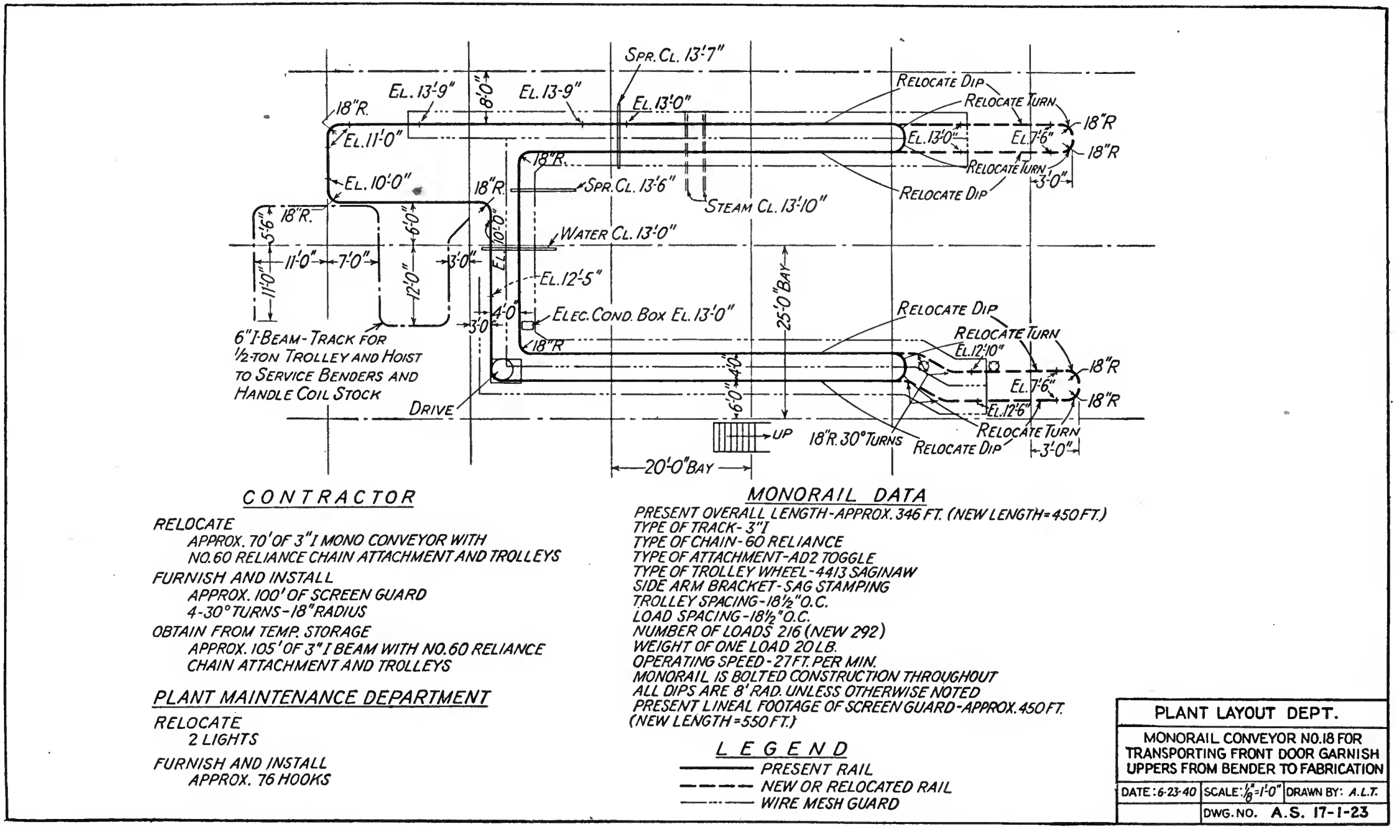



FIG. 65.—Installation drawing of conveyor rearrangement to accommodate layout change. The original drawing is altered to show those changes necessary to effect the rearrangement.

every expense should be considered in order to avoid any future request for funds, since additional requests, however small, not only are a reflection upon the production-engineering group but are frequently difficult to obtain.

Occasionally, new installation work is done so rapidly that the changes are merely marked on the floor in chalk, and the maintenance crew tacks up the overhead conveyor or positions machinery as rapidly as the locations can be indicated. Usually, however, a good deal of planning and scheduling of the installation and necessary construction work precedes the changes. A definite program is prepared, recording the equipment to be transferred and the time of moving. This not only sets a time limit on the equipment installation and makes for an orderly procedure, but it also assures the planning or production-control department that machines will be installed in time to meet production schedules or that they will not be removed before an adequate bank has been run off the old line.

**Installation Personnel.**—In setting up a new line or making a changeover, the installation work is often done not by the company's own plant engineering or maintenance department but by an outside contractor or equipment manufacturer. In such event, an agreement is reached which will be supported by (*a*) a list of all new machinery and equipment to be placed and any changes in the location of equipment now in the shop, (*b*) a specifications sheet showing how each type of machine is to be handled and installed and what work needs to be done in fitting it for production, (*c*) prints explaining the details of each installation, and (*d*) a schedule of moves.

In any contract with an outside company, it is wise, in listing the work to be done, to define clearly the work which the outside concern will do and that which the company's own maintenance crew will handle. In this way, one group cannot assume that the other will cover a certain portion of the installation because it is not included in his particular schedule. If the work of both is shown, each group can be certain what its job entails.

Companies which rely on outside firms usually lack the trained personnel to make such installations. Where production workers would otherwise be idle, they are used for this work unless the installation coincides with a vacation period. However, it has been found that production workers frequently consider this work in the nature of a quasi-vacation and do not exert themselves unduly. Arguments for a firm's doing its own installation work include the following:

The cost is likely to be less when the company has its own maintenance crew.

The maintenance men become familiar with the installation when it is put in and, therefore, find it easier to repair.

There is less need for elaborate paper work on contracts, prints, specifications, installation drawings, and the like.

Where speed and time are important in the case of hurried changeovers, it is frequently not practical to wait for an outside contractor.

By having the company's own men do the installation work, the presence of maintenance men is subsequently assured in case of emergency.

**Line Tryout and Pilot Lots.**—It is difficult to predict accurately on paper what will happen in the shop after machines and equipment have been installed. Production flow can be smooth only when there is follow-up by the production engineers to eliminate the "bugs." These may be technical difficulties in tools or equipment or may be problems in man power or material. There are no set rules for "breaking in the line," as circumstances will differ in every plant. However, changes and refinements in operations and their sequence are inevitable in any new line, and the first few pieces run through will be considered tryouts. Some concerns even set up test lines for study and improvement before making a production installation.

Most companies plan to get the line set up and a tryout made by a certain date. Many times, equipment or material is not all on hand at this date. Still, it is generally best to force the starting of the line before it is entirely ready, for production may never begin if the line tryout is held up for every detail. The tryout takes the form of putting a pilot lot over the line. The quantity of parts in this lot varies. They are always the slowest and most difficult to produce; for this pilot lot is, by its nature, a test of production design, processing, tooling, handling, layout, line balance, and materials inspection.

The plans of the production engineers have necessarily been directed toward the pilot lot from the very beginning. When this time arrives, the production engineers find themselves in the shop trying to iron out all the difficulties in the way of smooth production flow. Most plants at this stage have their best production men serving as sharpshooters or trouble men. The process engineer may have his own tool-trouble men in the plant to take care of all mechanical problems, but in these early stages he will be on the job himself as well. Every detail must be checked closely, as the shop is generally working with new designs, material, or equipment. With the building of the pilot lot comes the inescapable readjustment which accompanies the start of any new line.

**Turning the Line over to Production.**—In some cases, particularly where there are technical problems, several pilot lots, each a little larger than the preceding, may be run over the line before it is released by the production engineers. Other concerns immediately turn the line over to production as soon as the major difficulties uncovered in the pilot lot have been corrected. After the line has been turned over to production, there is still a period of "tuning up" before the job runs smoothly at the desired production rate. It is best not only to start a new line before it is completely ready but frequently to give it to production before difficulties have been entirely ironed out. During the period of initial production, a much higher schedule must be set than can be attained. Unless the early production schedule is always set at an unobtainable goal, it is certain to take much longer to reach the peak rate desired.

One process engineer tells the story of a line that, because of late delivery of one machine, was started at low production. Once the workmen hit this low rate, the superintendent was never able to pull the line up to the standard originally set for it.

At the outset of any new job, one superintendent says that his first effort is to get the quantity desired—to snap his

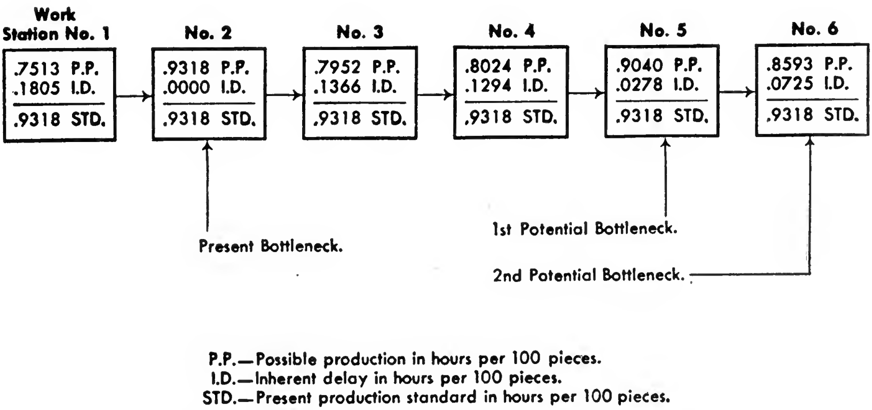



FIG. 66.—This chart used in analyzing existing or proposed line balance illustrates how the job or work station which consumes the most time automatically determines the standard rate of production. Attempt will be made to make the possible production equal for all operations so that there is no inherent delay, or idle balancing time. When studying prospective improvements, it is not good enough to increase the output at only one work station, if there are other potential bottlenecks. (*From Production Standards from Time Study Analysis, by H. G. Marchant.*)

men into the frame of mind to produce the volume wanted. Then he concentrates on cutting down scrap, and, finally, he goes after his efficiency rating (the ratio of labor dollars spent to labor dollars allowed).

**Rebalance.**—The initial balance of the line will also be considered temporary. As changes and improvements are made in methods during tryout and early production, a need for rebalance arises. Figure 66 shows a chart used as a record of the balancing times at different operations, and it also indicates the operations which should be attacked first in any improvement analysis or rebalancing. Once the line is running, new time-study observations are made. New standard times are set, and operations are balanced more accurately. Rebalancing will allow the line really to function as a unit with more efficient utilization of machinery, man power, and material. Rebalance is also in order whenever there is a change in the rate of production or improvement in the line that affects operating time.

**Layout Record.**—After a job has been set up and installed, the layout engineer makes a floor check of the line. From these data the equipment inventory is brought up to date, and the layout board is changed to show exactly the shop conditions. The layout engineer's house is thus put in order.

Plant layout groups sometimes make elaborate scale models of the line. Figure 67 shows an automobile-assembly-plant wall model. While this is more expensive, it allows a much better visualization in studying the layout for possible change, selling it to the various departments, or keeping shop personnel from making their own layout of equipment or banks. In any event, after the installation has been made in the shop, the layout should be brought up to date and maintained thereafter, perhaps in a form which is a little more elaborate than at first seems necessary. This is important in line production, for a change made anywhere along the line must still allow the line to function as a unit.

## EXPERIENCES IN LINE ESTABLISHMENT

By way of summarizing Part II, Establishing the Line, and showing that line production is not limited to large concerns, we may examine the procedures followed by several smaller companies in setting up their lines. These are in the form of case studies. Each is based on an actual situation encountered by a medium-sized company without a large staff of production engineers.

**Case I, Milling-machine Assembly Line.**—When demand increased for a small hand-operated milling machine, the manufacturer decided to change his assembly area to a line basis. The plant employed only 100 people. The plant manager, who had also designed the machine, performed what little

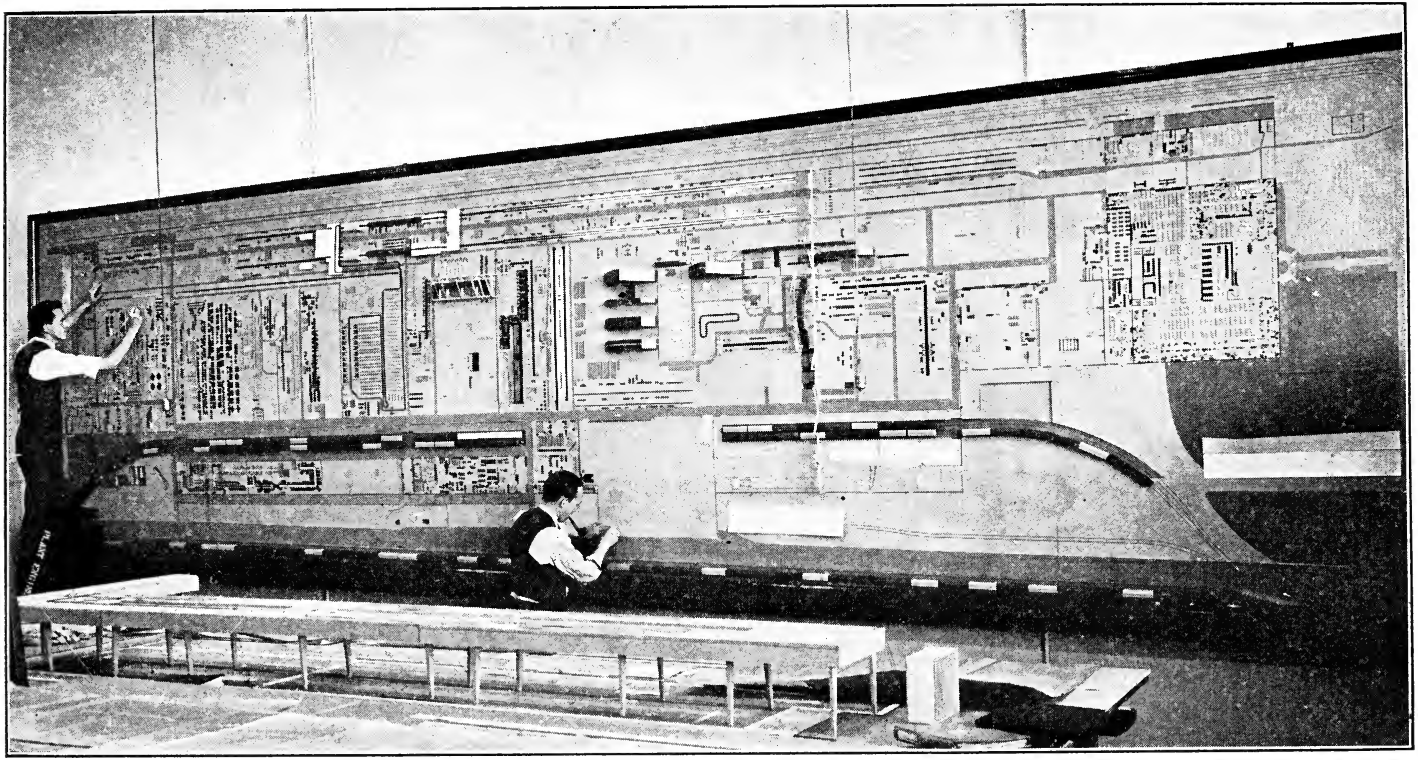


FIG. 67.—This scale model is a valuable aid to visualizing the plant layout. Painted blocks are used for machines, wires for overhead conveyors, and wooden models for the actual parts and assemblies. (*Courtesy of Automotive Council for War Production.*)

production engineering was normally done. His procedure in setting up the new line was as follows:

1. Determination of design and sequence of operations;
2. Breakdown of operations into sequence of parts;
3. Determination of storage facilities and floor space;
4. Layout;
5. Placing of operators.

1. The design of the machine was first examined. The machine had already been designed, but the manager wished to reconsider it from the standpoint of the assembly work and the few finishing operations that were to be done on the line. The manager was satisfied that the present design included no obstacles to easy assembly, such as heavy parts, inaccessible places, and an excessive variety of tools and attaching parts. The sequence of the necessary major operations was determined at this time. They included such operations as mounting column on base, mounting knee and head, and attaching motor arm.

2. With the aid of the assembly foreman, the manager then determined the kind and amount of each part required for each operation in the proposed sequence.

3. This parts-sequence list was used in planning the storage bins. For each item, the size, weight, and accessibility, as well as the number used and the frequency of fabricating runs, were considered with particular regard to storing each item at the place where it was to be used. At the same time, the rate of usage of these parts had to be known; it was calculated from the rate of production, based on the time of the bottleneck operation. Later, bins were designed specifically for this installation.

The floor space required was computed by allowing a central aisle wide enough for the machine and operator work space and long enough to have one machine at each major assembly station on the line. This space was subtracted from the total area to show the available storage area.

4. After the above calculation was made, further study indicated that the space would not permit one straight line.

This necessitated a U-shaped line with bins on only one side, as there was not room for a circular line, and zigzagging would have forced an undue height of stock bins. A scale drawing was made of the available space and cardboard templates made for machines being assembled and bins. The layout was arranged to feed toward the shipping platform with room allowed for an adjustment department. When drawn up, the location of operations and major parts bins was indicated on the layout.

The problem of transportation was considered at this time. A low, four-wheeled, metal dolly was chosen, on which the base could be mounted. Each machine could be pushed between stations.

5. The manager then turned over to the foreman of the assembly shop the problem of determining the number of workers and the operations each would perform. No time studies were made, but from his experience the foreman knew the relative difficulty and length of time of each major operation. Of the 15 operations, four were much shorter than the others, so that he combined them, placing one man on each two. This made 13 operators. Disregarding any timed balance, he divided the total assembly time of 40 hr. per machine by the 15 major operations, to obtain a rough figure for the time at each station ($2\frac{2}{3}$ hours per operation). At this rate, he could get out $8 \div 2\frac{2}{3}$, or 3, millers per 8-hr. day—a satisfactory output.

The workers were placed on the line under this arrangement. By later successive approximations, an adequate balance was obtained. A tight balance was not desired, because the demand was met by this method; regular times could not be obtained as in the case of scraping bearings; delays were frequent; and since the operators had come from the functional layout, they knew all operations on the line, and balance could be obtained by shifting them whenever necessary. In this way, almost any desired output could be realized by merely increasing the number of operators.

**Case II, Bottling and Packaging Line.**—The production manager of a plant manufacturing medicinal goods had the following experience in establishing his lines. Both the liquid and tablet bottling originally included counting and filling by machine, capping, sealing, inserting circulars, and packaging by hand. The original layout of the room consisted of several tables arranged by function and having no particular relation to each other. Bottles were carried between tables in boxes or cartons.

The first improvement was to divide the room into several product bays. U-shaped tables happened to fit neatly in each bay. The series of bottling operations were set up in each bay, and, though the operations were almost identical, this new arrangement required less transporting, counting, and packing and unpacking. A team of eight workers operated in each bay. Thus, the essence of line production was attained; for the first three operators each did a different job, and the entire bay was devoted to one product. The method failed to allow complete worker specialization, however, and operations had not been simplified. An increased rate could not be met unless the cycle time on the later operations could be shortened.

The production manager then set about to increase his output with the same number of operators. His approach was as follows:

1. Study the method;
2. Simplify the work;
3. Plan a new layout;
4. Balance the operations.

1. By studying the present work, he determined the sequence of necessary operations:

*a*. Air-clean bottle;
*b*. Fill bottle;
*c*. Place cotton (tablet bottles only);
*d*. Cap;
*e*. Label;
*f*. Carton;
*g*. Number cartons.

2. With the aim of having just one operation per worker, he classified the operations into two groups: those requiring one operator to meet the rate of production desired and those requiring more than one operator. He then studied the slowest operations for possible improvement and division. He did not at first combine operations because they were already long enough or too long to meet the desired time per operation.

3. The production manager then planned a line layout. Having previously substituted in his product bays a new machine that would quickly apply a fast-drying glue, he included this in his new setup along with a scheme for rapid interchange of the various filling machines, only one of which would be needed at a time. He wished the line to be sufficiently flexible to handle several sizes of bottles. After observing several packing lines in other companies and referring to a bottling engineers' handbook, he decided upon a canvas belt conveyor to transport the bottles. He calculated the length of the line by multiplying the number of operators (all on one side) by the space per operator and adding room for storage. From this he determined the length of belt needed. He then made a rough sketch of the floor space. The line was laid out parallel to the wall and for sanitary purposes started in a walled-off area.

4. When the equipment was installed, the operators were shifted from the U-shaped benches. After a few minutes' introduction, the operators began working along the belt easily and according to plan. All operators had been previously trained to perform all operations, and this plan was followed in the new setup also. It allowed for a shift of operators for balancing and enabled them to rotate their work when one job became tiring.

After the operators had become familiar with the new line, the production manager time-studied each operation. From this he was better able to assign work such as having one worker clean and help label, even though a small bank accumulated at both stations while the worker was on the other operation.

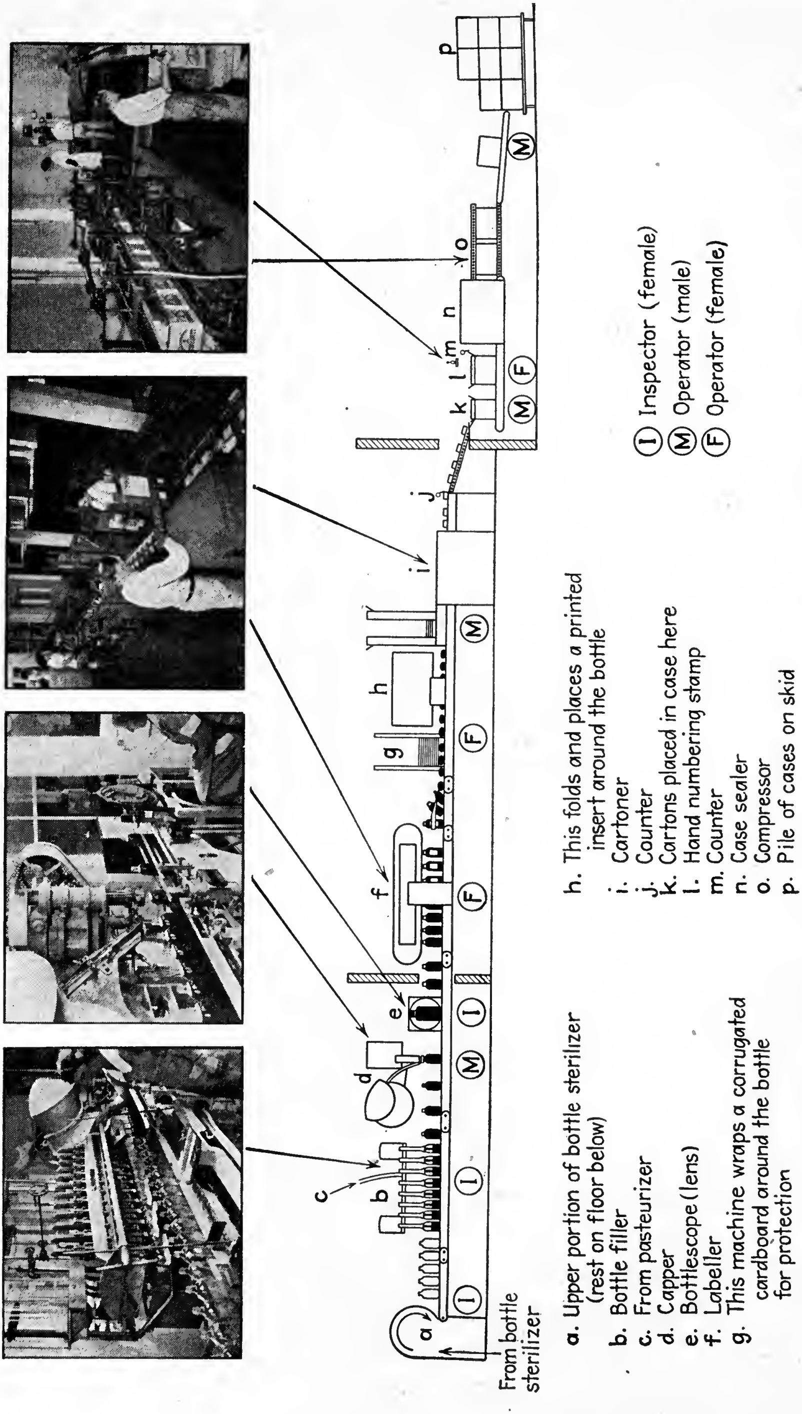



Fig. 68.—A typical semiautomatic bottling and packaging line commonly found in plants manufacturing consumer items with large distribution. (*Courtesy of Lydia E. Pinkham Medicine Company.*)

On several later occasions, this line was improved, until today it is not unlike the liquid-bottling line shown in Fig. 68.

**Case III, Rubber-product Assembly Line.**—A rubber company accepted a contract for an entirely new, large, inflatable product. The problem of making it most economically was in the hands of the operating manager, who assigned to a member of the industrial engineering department the carrying out of details. The work on this project divided itself into four major stages:

1. Development;
2. Job;
3. Team;
4. Pacing.

1. Since the product was new, the first step was to examine the specifications and parts. A completely assembled sample was taken apart piece by piece in order to determine exactly what material was used, how many parts there were, the patterns to which they were cut, and how the parts and subassemblies were joined. With the product development group doing most of the work, the industrial engineer guided the processing of material and saw that an acceptable quality was cut and assembled into one full-scale model. Only already available equipment was used, and the assembly was done outside of the regular production departments. With the knowledge gained from this preliminary study, the materials, the shapes and sizes of parts, and the methods of performing each operation were standardized.

2. Production was then begun on a job-shop basis, all operations being done in the assembly departments except processing the rubber sheets, cutting to patterns, and testing the inflated units.

3. The team stage was gradually worked out. It consisted of assigning operators to specific jobs at their worktables and passing the parts and subassemblies to the next table in the sequence when each operation was completed. Actually,

much of the work was done by teams of workers at each table because of the size of the unit and the amount of work involved in each operation. To aid in this, a process-flow chart analysis with the customary questioning approach (elimination, combination, change of sequence, and simplification) of the motion economist was employed. Each operation, storage, and transport was studied, as well as the time of each operation and distance of travel. The job-shop operations were divided into specific assignments for each worker. Rough time estimates were used at the outset to apportion work for proper balance. These were later checked by time study, and necessary changes were made.

4. This sequence of bench stations with intermittent passing resulted in considerable savings. However, the flow was not uniform, and there were considerable waste motions and idle operator time, a condition which led to placing the whole job on a paced conveyor line. Elemental times for each operation were totaled, and the amounts converted to man power required to produce one unit. This latter figure times the daily rate of production determined the number of operators necessary. Jobs were broken down still further to give each operator as nearly as possible the same amount of work.

A scale drawing of the room was laid out on layout boards and cardboard templates cut out for the various pieces of equipment. Though this step was not necessary to arrive at the completed project, it was felt to be a definite aid in attaining the improved result. Actually, three lines were planned for the space, since part of the operations were to be set up for a rate double the cycle time of the main line. This was no particular problem, because the main assembly had to be interrupted anyway for inflation tests before final sealing and attachment of accessories. Wide belt conveyors were set up in another wing of the plant. Certain equipment was transferred ahead of time with all assembly operators moving to the line together. The line was run slowly until workers became familiar with the work that was to be done at each station. During this period, the balance was constantly adjusted by revising the operation breakdown for smoother and more efficient operation.

**Case IV, Gunstock Fabricating Line.**—A plant manufacturing wooden toys decided to set up a production line to manufacture army gunstocks. Since the company had always worked on a job-lot basis, an outside consulting firm was called in to help. The production engineer assigned to the company was given a free hand. The plant superintendent, who had intimate knowledge of woodcutting, and the machine shop assisted him in his work.

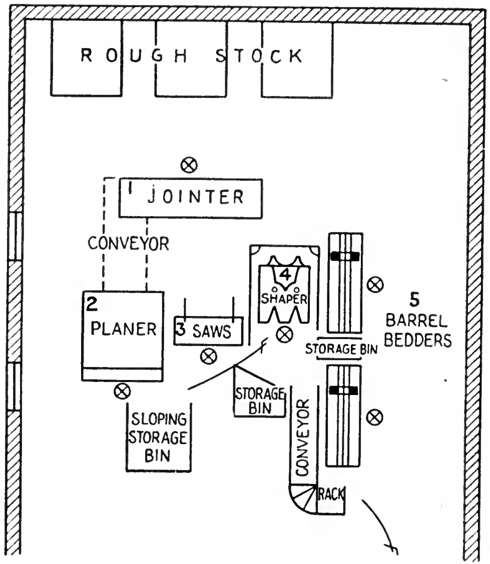
The actual procedure he followed can be classified into eight major steps:

1. Design study;
2. Methods study and sequence of operations;
3. Machine and tool design and construction;
4. Layout;
5. Equipment setup and adjustment;
6. Time study;
7. Balance;
8. Final adjustment.

1. The production engineer first studied the product design and specifications, attempting to eliminate all unnecessarily close tolerances on unimportant dimensions and to simplify the job.

2. He then listed every operation necessary to produce the finished stock. Next, he tried to eliminate, combine, rearrange, and simplify the operations and to obtain the best sequence. He considered, for example, holding the piece so that cuts would be located from a few key points on subsequent operations, eliminating hand finishing operations, and combining several cuts on one machine. Several lists were made before his improved methods seemed ideal.

3. The next step was to design new tools and equipment or to modify what was already on hand. He consulted the plant superintendent, the machine shop, and woodworking machine handbooks and methods. Tooling was created for ease and economy of operation, for speed and long-period




DESCRIPTION OF OPERATIONS

1. Joint one side
2. Plane to thickness
3. Saw ends to length
4. Shape to approximate contour
5. Cut barrel and clearance grooves
6. Make receiver cuts
7. Bore 2 holes and route for lug
8. Shape grip-top and bottom
9. Shape sides-grip to tip
10. Shape top of butt
11. Shape bottom of butt
12. Shape sides and bottom-receiver to lower band
13. Shape sides and bottom-lower band to tip
14. Shape top and bottom-trigger to lower band
15. Cut upper and lower bands
16. Cut tang and drill
17. Cut thumb piece cut
18. Cut swivel plate cut and drill
19. Saw to final length
20. Drill holes (4)
21. Clear, bevel, shave and make other hand cuts
22. Rough and finish sand
23. Oil bath

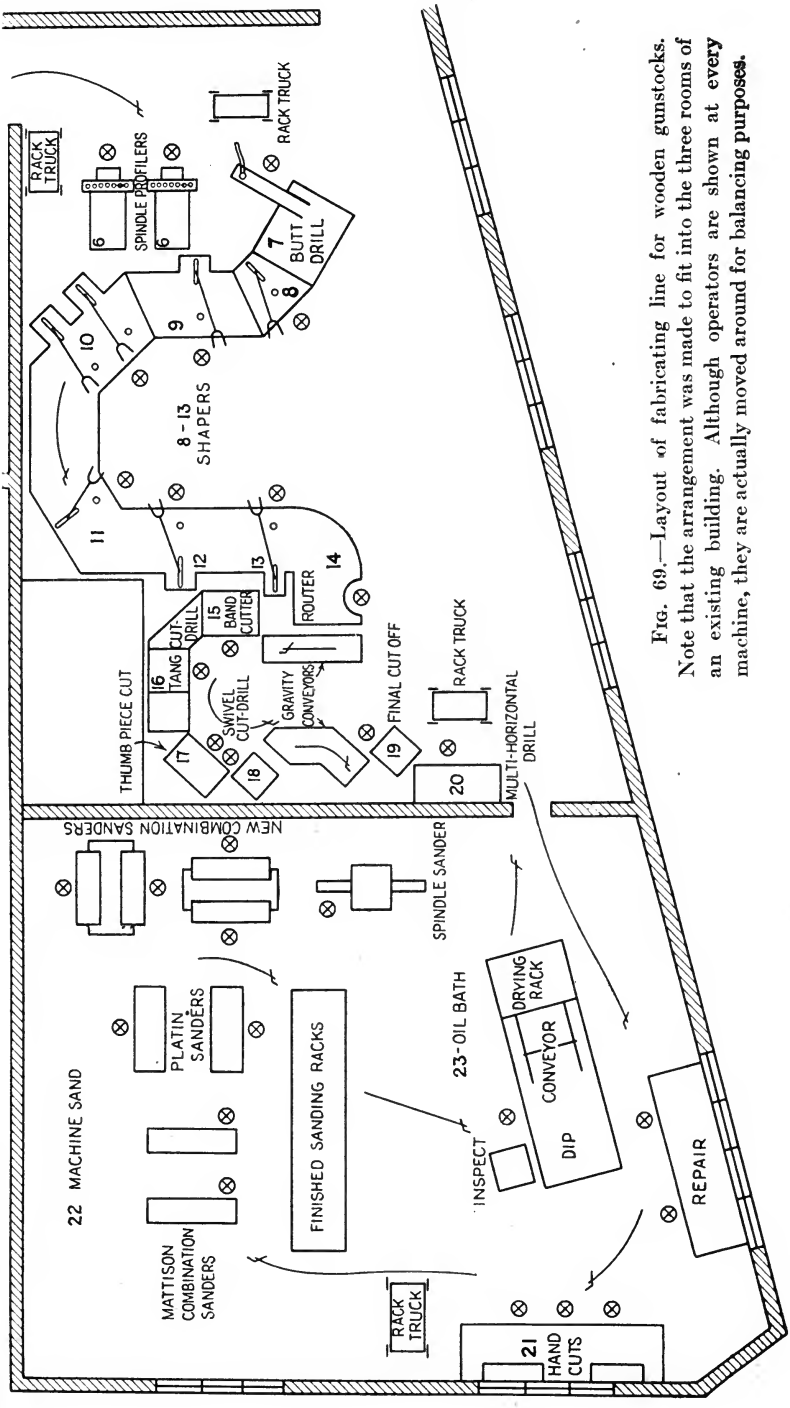



Fig. 69.—Layout of fabricating line for wooden gunstocks. Note that the arrangement was made to fit into the three rooms of an existing building. Although operators are shown at **every** machine, they are actually moved around for **balancing purposes.**

performance. The rate of production was a constant guide. For each new piece of equipment was added a safety factor for breakdowns which related to the type of cut. Detail drawings were sketched for the necessary changes and additions in equipment and were turned over to the machine shop or purchasing office, although other improvements were still to be made later on.

4. While the new equipment was being secured, the production engineer proceeded to plan the layout. Special consideration was given to

*a.* Operators available;
*b.* Stock receiving and shipping points;
*c.* Shape of space allotted;
*d.* Machine sizes and sequence;
*e.* Materials-handling system;
*f.* Operator and storage space;
*g.* Safety;
*h.* Working conditions (noise, dust, lighting).

Cardboard templates on a layout board were used. Many changes were made so that the layout was not definitely established until the equipment was ready for installation. The final arrangement is shown in Fig. 69.

5. The next step was the installation of the equipment, which was accomplished by the plant mechanics and repair crew. A tryout of each machine was made as soon as it was in place. A nucleus of operators was selected. The production engineer himself instructed them in the techniques of each operation. Production was then begun in small lots while improvements were made in machine setups, tooling, and motions of the operators.

6. As soon as the stocks could be run through correctly cut, without delays, the production engineer took time-study observations of each operation. This was done primarily for purposes of balancing the line. It also afforded knowledge of limiting machine capacities as a guide for possible production rates on subsequent orders and acted as an incentive to

workers, for the time information on each operation was posted at its proper station.

7. In balancing, the engineer ignored all but productive operations, for he planned all handling between operations that required rack trucks and all maintenance and tool sharpening to be done by other workers. However, where there was unavoidable idle balancing time, some of this facilitating work could be assigned to line operators. Exception to this was on the sanding and repair operations, which could not be accurately timed.

8. Once the balance was worked out, the exact number of workers were brought into the line and trained by the earlier operators. Regular production then began. Further adjustments in tools, working methods, and handling were made while the inexperienced operators were breaking in. The production engineer constantly worked for better operation until the line climbed up to full-rate production, when it was turned over completely to the plant superintendent.

# PART III

# OPERATING THE LINE

## CHAPTER IX

## ORGANIZATION AND PLANNING

Part III of this book deals with methods of operating the line once it has been set up and tested. The planning of the line and its installation have already been described. The operating phase will now be discussed.

The objective of this second aspect of line production is to produce the desired amount of output when required and in the condition specified. Not only are the technical operations as performed by the production department here significant; production planning and scheduling, material control, quality, maintenance, and line personnel are functions also directly contributing to this objective.

### SHOP ORGANIZATION

The subdivision of labor into a number of small operations makes it possible to utilize the skills and aptitudes of each individual to the best advantage. Each worker will be required to know only enough to do his own job. As a result, not only is it necessary to have proper supervision, but, in addition, a group of trained functional specialists should be on hand to serve or to facilitate production.

**Functional Specialists.**—The nonproductive work of the functional specialists may be so large in amount as to keep three or four men busy serving the line for every producing operator. We are not speaking here of the group responsible for setting up the line but are referring rather to (1) the maintenance workers who keep every piece of production or handling equipment in working order, remove waste material, and keep the line supplied with the proper tools; (2) the materials handlers who feed material to the proper station at the right time, transfer it between lines, and remove it from the end of the line; (3) the groups who schedule the production lines and coordinate them with each other and with outside demand; and (4) the many other functions concerned with controlling satisfactory material and adequate operators. The objective in segregating these functions is to relieve the line employees of all nonstandardized work and to allow them to devote their attention solely to performing the operative task for which each has been especially trained.

**Production Supervision.**—Authority is generally delegated to superintendents and general foremen and by them to the lesser supervisors such as assistant foremen, group leaders, utility men, job setters, and the like. It is at this lower level of supervision that much of the success of the line depends. These supervisors are close enough to their assigned operations and sufficiently familiar with the workers to be of immediate and practical assistance. Frequently, they act as relief operators, machine adjusters, instructors, and stock men along the section of the line to which they are assigned. They are particularly important in caring for anticipated interruptions which might hold up the line. A foreman responsible for a line of 25 to 35 workmen might have four or five such assistants to assure smooth operation of the line.

The foremen themselves are not so highly skilled as in job-lot manufacture, inasmuch as a considerable part of their responsibility is placed in the hands of the functional specialists. They may not even know how to operate all the equipment in their departments. They do not require the technical skill of the functional shop foremen, for all engineering problems are taken care of when the line is set up. The production-line foreman is responsible for the output of but one or a few parts, and he soon becomes familiar with their details. As a result, he requires less than normal technical ability. Moreover, the regularity of flow is an automatic aid to the foreman, as any delays or interruptions will be immediately revealed by a variation. However, to the extent that there are less skilled workmen on the line, the foreman's task of superintending his workers is thereby more difficult. Line production requires foremen to be good leaders and able to deal competently with individual personnel problems.

The assignment of authority to each foreman over a production line is of particular significance. It gives him

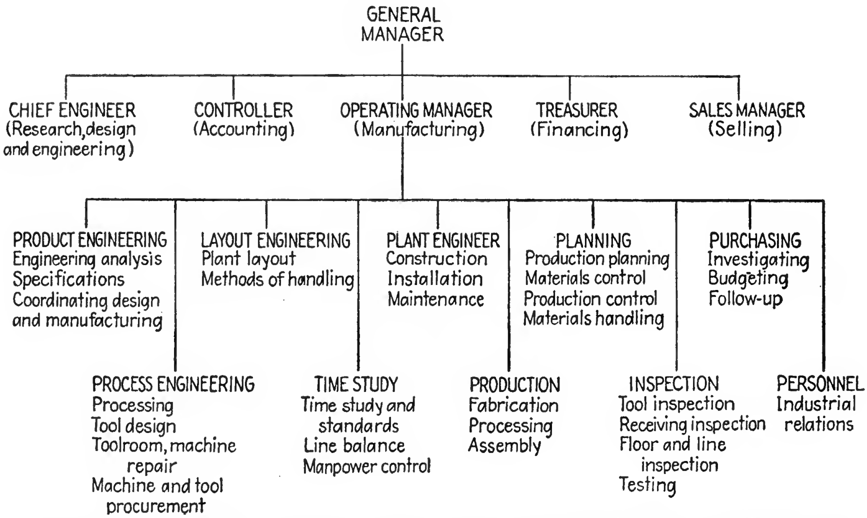



Fig. 70.—Typical organization for a medium-sized metalworking plant arranged for line production.

complete control over the product and fixes upon him the responsibility for the entire sequence of operations, thus making him an executive in his own right.

## MID-ZONE ORGANIZATION

As has been stated before, the two phases of establishing and of operating the line require two different organizational groups. Their purpose is not the same, and their outlooks also differ. As the production engineering and installation activities decrease and as operating controls begin, some individuals concerned with the setting up of the line may transfer to the second group; but it is essentially a new organization that performs these subsequent functions. Certainly, when an outside consultant or equipment manufacturer makes the installation, an entirely different group will control the operation of the line.

In larger plants each function in establishing and operating the lines may be performed by a separate department. Figure 70 shows this. Naturally, smaller plants combine these duties among the same persons, the organization structure frequently depending on the products being made. For example, one company organized throughout by types of product placed a single officer in charge of process engineering, layout, balance, and the scheduling and control of production.

When organization changes accompany a shift from job-lot to line production, the departments which tend to gain in importance are plant layout, time study, methods and equipment, materials control, and maintenance. Conversely, work becomes easier for the departments of production, production control, cost control, and inspection.

## MANAGEMENT RESPONSIBILITIES

With the line as a unit, whenever the product changes or a method is improved, the entire line is involved. To accommodate even small changes the line may have to be rebalanced throughout to become again a coordinated unit. Management's willingness to accept extensive change and the necessity at times of radical conversion or readjustment is an outstanding aspect of line production.

Another responsibility is that of dealing with emergencies. When lines are scheduled tightly with a great many specialized operations, it is important to foresee all contingencies and to visualize from the beginning all possible difficulties. Safeguards may be provided or alternate solutions planned and retained in readiness for the difficulty if it arises. By thus eliminating the element of surprise, management can make quick and yet correct decisions.

A further feature of line production is timing. In setting up the line, failure to finish one aspect of the work on time will hold up others, and delay in one place multiplies subsequent difficulties so that initial production is delayed. In operating the line, it is the relative timing of operations and of material movements rather than the speed which brings major benefits.

The interdependence of various functional groups upon each other is again emphasized in line production. From the greater specialization of workers on the line up to the highly organized operating controls, almost everyone in the plant depends on others for the proper carrying out of his work. Line production is an impossible setup if management cannot influence individuals willingly to coordinate their efforts.

## PLANNING

Probably the most important single responsibility in line production is that of planning. If the line is to be arranged for a desired rate of production, to be set up as a coordinated manufacturing unit, and to be properly controlled in operation, planning is an inescapable necessity.

Coordinate with line establishment and operation are different types of planning. The first type involves scheduling the different production-engineering steps, whereas the second type involves (1) deciding when and how much of each product will be manufactured and (2) coordinating the incoming material and operating departments to conform to the plan. Both activities rest upon an initial over-all plan incorporating the expected volume of sales. From this forecast, rates of production are determined for each line.

In establishing the line, in addition to the rate of production and the total quantity to be produced, the date or moment when it must be in operation is a major consideration. Plans to initiate production promptly are established with the above data as a basis. Next, a time is set for completion of the first subassemblies, for tryout of the line, for installation of the layout, and for the several stages of production engineering.

Thus many technical functions or specialized activities are integrated to meet the time objective. Actual schedule charts may be of considerable aid during this period. Figure 71 shows a schedule and control sheet that has been a valuable aid to the aircraft industry in getting its pilot assemblies and

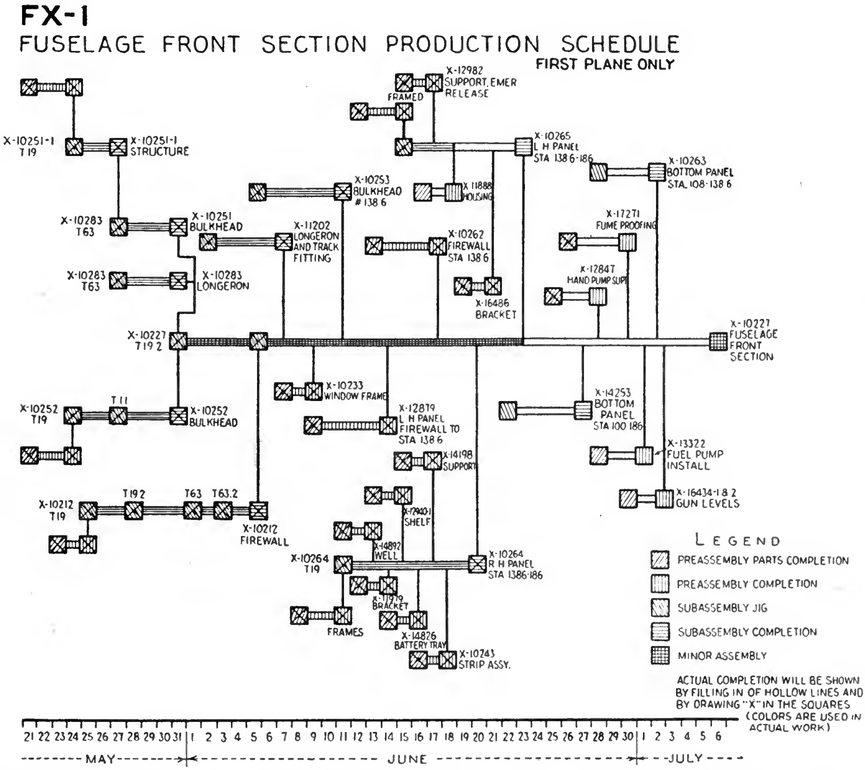



Fig. 71.—Schedule and record of completion for pilot job in an aircraft plant. (*From Graphic Management Control of the Navy Bureau of Aeronautics.*)

subassemblies made on time. Figure 72 represents a method of follow-up on tools and dies to ensure their arrival in time for machine tryout.

In operating the line, proper planning is again required. A program or master plan to which the lines can be scheduled is based on the total number of completed units of each type to be produced for a certain period and on the distribution of this volume over the period. Although the plan is not subdivided into departmental schedules initially, it should be sufficiently accurate and far enough in advance to act as a reasonable basis for production schedules.

There is not room for a lengthy discussion of the methods by which such a program can be organized. In general, the basis of this over-all plan is found in market surveys, sales forecasts, records of past orders, statistical studies, or a specific

**TOOL AND DIE FOLLOW-UP**

PART NAME *RADIATOR TANK (half)*

| MODELS | S-41 | S-43 | | |
|---|---|---|---|---|
| USAGE | 1 | 1 | | |

DATE ENG. REL. REC'D *11/17* ENG. LINEUP *Plant #1 make, Bush St. and Plant #3 assemble*

| TOOL NO. | TOOL NAME | DESIGN | | TOOL VENDOR | PROM. | ENG. CHGS. | | TRYOUT | | DEPT. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | START | COMP. | | | CHG. | DATE | START | OK | |
| — | Sq. Shear | | | | | | | | | |
| D1 | Draw | 12/1 | 12/10 | Parker Tool & Die | 1/20 | "A" | 1/10 | 1/23 | 1/30 | 79 |
| D2 | Restrike | | | " | | | | | | |
| D3 | Trim & Pierce | | | " | | | | | | |
| D4 | Pierce | | | " | | | | | | |
| D5 | Form & Pierce | | | " | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |

SAMPLE PARTS

| ORDERED | | MADE | | FORWARDED TO ASSEMBLY DEPT. | | | |
|---|---|---|---|---|---|---|---|
| DATE | AMT. | DATE | AMT. | DATE | AMT. | DEPT. OR PLANT | OK'D |
| 1/2 | 50 | 2/5 | 50 | 2/6 | 25 | Bush Street | 2/9 |
| | | | | | 25 | Plant #3 | 2/10 |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

REMARKS

*Dies received 1/22 at Plant #1.*

PART NO. *674981*

Fig. 72.—This tool and die follow-up record is used in planning the establishment of the line. It illustrates how important the details become regarding every tool in order that it be on hand and in working condition when initial production is scheduled.

delivery schedule required by the purchaser. Steady production is particularly desirable. Companies with seasonal problems often find it much more expedient to level off sales peaks by warehousing their finished products. Some concerns operate at a uniform rate regardless of orders so that they may benefit from an even flow of production.

The operation of the line is controlled by periodic issues of approved production schedules. These schedules are subdivided according to the various products, parts, departments, and material requirements. They take a variety of forms and names, such as shop schedules, production releases, or departmental orders. As these production schedules cannot always be issued early enough, material authorizations or purchase budgets may be used to control purchasing commitments.

In addition to the over-all production planning and scheduling, the planning department frequently has control over two other interdependent functions: (1) materials control—regulating the movement of raw and finished materials from outside sources, and (2) production control—scheduling, dispatching, and following up the fabrication and assembly of material and parts into finished units. Since materials must move along the line in order that production may be accomplished, some centralized group must be responsible for synchronizing this flow of material into the plant and through the various departments to the shipping room.

The following examples are practical instances of over-all planning and scheduling of production as practiced by several companies.

**Automobile Manufacture.**—The introduction of new models or resumption of seasonal activities is preceded by a seasonal forecast by the management. This includes an estimate of the potential seasonal demands, a study of available equipment and tools, purchase of additional tools wherever required, and provision for additional manufacturing facilities if expansion is indicated.

The actual work of planning becomes activated by a 90-day building schedule from the sales department, giving the quarterly sales requirements, domestic and export, by body and types. This schedule is firm for the first 30 days and tentative for the next 60. It is issued every month, at which time quantities are readjusted to take care of changes.

About the twenty-fifth of the month, the sales department submits a definite schedule for the first 10 days of the following month, showing specific daily shipments and enabling the planning department to establish the flow of body styles.

The 10-day schedule is followed by a daily shipping schedule, issued 3 days in advance and showing exact specifications as to body styles, color option, wheels, trim, and other variable details. Thus the planning department regulates its car building with the following five schedules worked out with the management and the sales department: (1) broad plans for the entire season; (2) tentative 90-day sales schedules; (3) definite programs for each 30 days; (4) shipping schedules for the first 10 days of the month; (5) daily shipping schedules with complete specifications.[1]

The planning department of another concern in the automotive field functions in very much the same way. The various orders or contracts are incorporated in a plan covering production on the orders over the months allowed for their completion. The monthly production rate and the production per day, as well as the cumulative total for each, are specified in this production schedule. This schedule, also announced for a 90-day period and revised monthly, is based on the latest developments and any difficulties with production, equipment, or materials. Thus each monthly breakdown is a true schedule. The second month is tentative and the third but an approximation. Figures beyond this are just rough estimates and will undoubtedly be altered by changing orders or contracts. The monthly schedule for each item is itself subdivided into a monthly and daily schedule for each part and each department.

**Military Tank Manufacture.**—One tank plant used a general authorization issued periodically by the central executive office and based on government orders. The building schedule covered only about 4 weeks. However, it was generally accompanied by a material authorization similar to that shown in Fig. 73. Though the schedule for building and for spare parts was definite for only the first month, the prospective schedule was firm enough to serve as a basis for scheduling purchases from outside vendors. The figures for production banks were given to aid the planning department in determining the proper amount to hold in storage in order

[1] GESCHELIN, J., "Synchronizing Materials to the Assembly Line Demands Exacting Attention," *Automotive Industries*, Vol. 63, No. 14, p. 482.

to afford the desirable number of days' protection. The bank figures were specified a month in advance so that the proper amount of stock would be on hand by the time the schedule called for its use.

**Radio and Refrigerator Manufacture.**[1]—This is characterized by large runs of a limited number of models. Models are subject to frequent and sudden changes, as competitors

MATERIAL AUTHORIZATION # 13
(Based on General Authorization # 20)

REVISED APRIL 23, 1943

| MONTH | BUILDING SCHEDULE | SPARE PARTS IN SETS | PRODUCTION BANKS 3 DAYS | 5 DAYS | 10 DAYS | 15 DAYS | 20 DAYS | 30 DAYS |
|---|---|---|---|---|---|---|---|---|
| SCHEDULED THROUGH APRIL | 3988 | 40 | 81 | 139 | 270 | 405 | 570 | 715 |
| | | | | | | | | |
| MAY | 715 / 4703 | 7 / 47 | 75 | 125 | 250 | 375 | 500 | 654 |
| JUNE | 654 / 5357 | 7 / 54 | 72 | 120 | 240 | 360 | 480 | 624 |
| JULY | 624 / 5981 | 6 / 60 | 72 | 120 | 240 | 360 | 480 | 624 |
| AUGUST | 624 / 6605 | 6 / 66 | 72 | 120 | 240 | 360 | 480 | 624 |
| | | | | | | | | |
| BALANCE (623 MONTHLY) | 3538 / 10143 | 35 / 101 | | | | | | |

FIG. 73.—Material authorization which precedes the actual production schedule allows those responsible for getting the material on time to make purchase commitments. The slanting line separates monthly from cumulative figures. Note that the banks are based on figures for the following month's production.

bring out new designs or the company's own research department develops improvements. The seasonal demand for the two products is complementary.

For each of the models decided upon for a season, an estimate of probable sales forms the basis of a weekly release, covering a quantity and a duration determined by the sales estimate. This schedule is translated into a detailed quota of daily deliveries for each department.

The purchasing department's operation is based on a schedule of material releases similar in principle to that used by the operating departments. New schedules are released monthly, a week in advance of the expiration of the old. Very

[1] DUTTON, H. P., "Production Control," *Factory Management and Maintenance*, Vol. 93, No. 6, June, 1935.

few parts are carried in stock; the risk of change of models is so great that the aim is to consume the entire stock of parts for a model at the end of every run. Should the sales of any model prove disappointing, its schedules are shortened to use only the materials for which firm orders have been placed.

Schedules and budgets are made up in a central planning department. Deliveries are also reported to this department.

**Miscellaneous Manufacture.**—An electric-appliance company forecasts production three years ahead, thus laying plans for changes in production lines, buildings, or equipment. The more immediate planning begins with a quarterly estimate supplied by the sales department. The manufacturing division uses it as an aid in planning purchases and in the fabrication of parts. With this estimate and charts showing purchase orders received, production output of fabricating departments, and stock on hand for all items, a study is made which results in a definite factory schedule, including the assembly lines, covering a 10-week period. This is revised every 5 weeks, or oftener if incoming orders vary too widely from the estimate.

Still another company producing light industrial and medical chemicals controls its packaging lines by a weekly schedule.[1] Products are usually made up in economical batches based on sales estimates and trends, but each Thursday a program is issued to cover the following week's assembling runs. The order of jobs is determined by the amount of material already processed and on hand, similarity of containers, and cost of changing the line to the new setup. Copies of these schedules are distributed to those who are responsible for having on hand at the right time the bulk, containers, labels, cartons, and operators required.

## EXECUTIVE READING

"Aircraft Tool Planning," *Aviation*, Vol. 42, No. 4, p. 144; Vol. 42, No. 5, p. 179. Article by R. H. Luders.

"Flexible Production System Holds Plymouth Inventory to Minimum," *Automotive Industries*, Vol. 63, No. 20, p. 712. Article by A. H. Paterson and J. Geschelin.

[1] KIMBALL, W. M., "2000 Products to Package," *Factory Management and Maintenance*, Vol. 97, No. 4, p. 42.

# CHAPTER X

## MATERIALS CONTROL

The right kind of material, correct in amount, must be at the point of use when it is needed. Usually, questions of quality specifications and price are left to the engineering, inspection, and purchasing groups, but the problem of having these materials available to meet production schedules is the function of those responsible for materials control.

**The Importance of Materials Control.**—The work of materials control is to coordinate with planned production schedules the movement of material from outside sources. In line production, this is imperative, for, in most cases, the line has been set up for a definite rate to meet a predetermined forecast or budget of sales. The lines will operate at this established rate, regardless of daily sales fluctuations. Since this means a steady output emerging from the end of the line, there must also be a uniform feeding-in of material at the beginning of the line. One of the great opportunities for savings offered by line production is lost if the materials-control group does not tune its incoming deliveries to the production schedules, for otherwise excessive amounts of stock are carried in the plant.

If production lines are to operate smoothly, materials handling should be completely synchronized with production rates. In fact, successful planning, scheduling, and control of material are the most significant functions in the operation of production lines. Fabricating lines cannot operate without their correct raw stock. Assembly lines must have on hand all of the component parts, or the unit cannot be assembled. It is not enough to have 99 pieces if the hundredth is missing; for even though it is only a washer or a bolt, the shutdown of the entire line, or at least costly delay, may result. And it is usually the small parts that are overlooked; major components seldom run short. Even supplies must be watched carefully, for they, too, can cause the line to stop.

A large number of interplant shipments increases the importance of materials control. This generalization applies more to the larger mass-production plants, which are often set up on the flow principle throughout, than to the sporadic lines in smaller companies. Many such factories specialize only on the assembly of one product or devote themselves to the fabrication of a certain number of parts. Where volume is high, it becomes more economical to allow these plants to specialize and supply, or to be supplied by, other specialists. This means that material shipments from hundreds of vendors or subcontractors must be coordinated with the production schedules of the plants which are being served.

Even more important is the investment tied up in material. To be sure, this would be greater were it not for line production, but quantity production of any sort will involve large amounts of material, and it is essential to have this investment rigidly controlled. Moreover, loose control may also require excessive floor space for storage.

## REQUIREMENTS

There are basically two methods of materials control. The first is buying and manufacturing material in accordance with requirements determined from a master schedule or program. The second is buying for stock in anticipation of later usage and replenishing the stock pile when it reaches a predetermined minimum. The second method is generally referred to as the *maximum-minimum* method of inventory control and is perhaps the most systematic and simple type. It definitely has its place in merchandising, warehousing, and controlling service parts and in some job-lot shops. In most manufacturing plants and certainly in companies using line production, this method of buying for stock and controlling balanced by a max-min has been discarded in favor of control by *requirements*—buying for production needs only. By this means it is possible to coordinate the even flow of material into the line without holding excessive amounts on hand. This may be visualized from Fig. 74.

**Determining Requirements.**—Before the material can be ordered or scheduled into the plant, accurate determination of

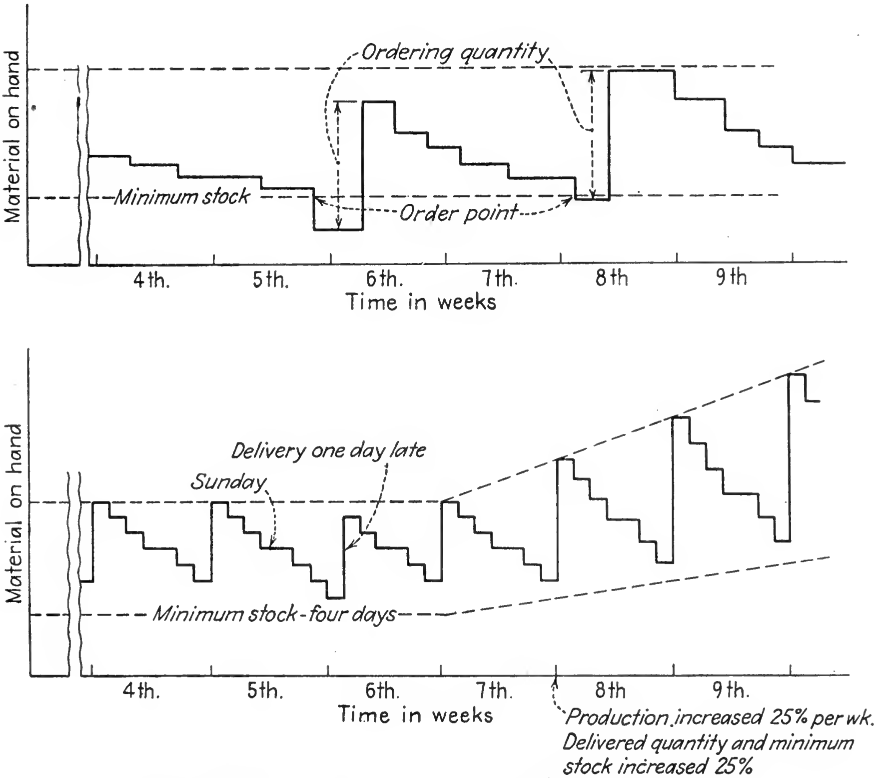



FIG. 74.—Comparison of materials control by the max-min stock limits and by the requirements method.

the quantities needed must be made. This is done by breaking down the master production schedule (as given in the authorization, building schedule, or production order or release) into a daily or weekly schedule of needs. The schedule of finished units for the month is divided by the number of working days in that month to get the daily schedule for a particular product.

$$\frac{\text{Monthly production}}{\text{working days per month}} = \text{daily rate of production}$$

To know the daily needs of the various items or components, one must determine the number of pieces of each item in each complete assembly. The finished product ready for shipment is usually spoken of as the *unit*, or the *complete unit.* The term *usage per unit*, or *usage*, may be applied to the number of pieces of any one item in each complete unit. If there are four legs on a table, then the usage per unit is four, provided all four legs are the same. The usage per unit of any item multiplied by the daily rate of production of complete units equals the daily requirements of the item.

Usage per unit $\times$ daily rate of production = daily requirements

If an item is used in more than one complete unit, the usage will be determined for each different unit of which it is a part. If several models of tables use the same style of leg, the usage per unit should be determined for each model. For example, if the daily production of tables, Models TA, TB, and TC, equals 10 each, and they use four, four, and six legs, respectively, then the daily requirements for table leg #6214 equals $(10 \times 4) + (10 \times 4) + (10 \times 6) = 140$ pieces.

PART NUMBER: 6214 PART NAME: Leg, Table

| Models | Usage per unit | Daily production | Daily requirements |
|---|---|---|---|
| TA | 4 | 10 | 40 |
| TB | 4 | 10 | 40 |
| TC | 6 | 10 | 60 |
| | | | Total 140 |

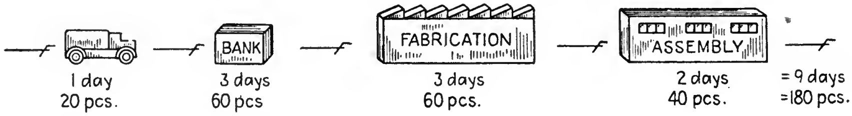
This calculation of requirements involves parts lists, parts record cards, and often tabulating equipment, for the usage (both in quantity and in type of assembly) of every part must be known and translated into a schedule of requirements. In a complex unit this becomes a sizable problem. Consider an airplane, for example, which is composed of groups of parts, or locations. Location 12 might consist of 3 major assemblies, 8 to 10 minor assemblies, and 30 or 40 attaching parts. Each major assembly is composed of a certain number of subassemblies and attaching parts, and every subassembly is itself made up of several parts. When it is understood that some of these parts may be used in several different assemblies at different locations and even on different planes, and that a part number may answer to a name such as BAC1307-95521, the magnitude of determining the proper requirements becomes evident. This grows more complicated when service or spare-parts orders are to be included; for certain extra subassemblies, parts, and parts of the subassemblies will then have to be incorporated into the requirements.

The requirements for purchased parts and materials must be specified to cover an indicated period of time. After the daily requirements have been determined, they must be multiplied by the number of days to be covered in the delivery period.

$$\text{Daily requirements} \times \text{days between deliveries} = \text{quantity per delivery}$$

**Storage of Incoming Material.**—From the standpoint of reduced inventories, the ideal here is a continuous feeding of parts and materials into the plant. On many large, bulky components, this is almost essential. In automobile assembly plants, for example, car bodies are delivered from the body builders at the rate of one trailer load every 2 or 3 min. However, such conformity is seldom possible, and the delivery period varies from this extreme frequency to as long as 2 or 3 months for small standard parts that cannot be delivered in small quantities, special orders of certain material, or larger lots where the supplier must be allowed an economical run.

In ascertaining the requirements, it is necessary to work backward from the date of completion, through the float on the lines, in safety banks, and in transit, to determine, from the date when finished units are wanted, the date when each item of material must be shipped from the supplier. For example, the production schedule might call for 10 completed units per day. Assuming that two pieces of a certain part are used in each assembly, 20 pieces are used per day. If the time to assemble the unit is 2 days, the time to fabricate is 3 days, the in-transit time from the vendor is 1 day, and if the manufacturer wishes to maintain a 3-day safety bank ahead of his production, then there are 9 days' requirements, or 180 pieces, in the entire system.




There are several terms used rather loosely in this connection. The term *float*[1] generally applies to the material in process on the line. It may also be used, as is the term *system*, to mean all the parts of any one kind in the whole plant or several plants and sometimes includes material in banks and in transit. *Bank*[1] and *normal stock* generally refer to the inventory stored ahead of production as a *buffer* or *cushion*, though bank is loosely used to refer to any storage of material. *Lead time* may mean the number of days ahead of scheduled completion that the material must be shipped from the supplier. Since each plant has its own terminology in this respect, it is difficult to establish specific definitions.

A float larger than that needed for balancing or for storage banks along the line acts as a protection or reserve against delays. A bank ahead of production acts as protection against late deliveries. The size of the incoming bank varies with the likelihood of serious delay and depends upon such factors as (1) the frequency of delivery from the supplier, (2) the distance between the plant and the supplier, (3) the size of the part, (4) the frequency of engineering changes or the danger of obsolescence, and (5) the dependability of the supplier. The bank is determined as the number of days' or minutes' protection that is wanted.

Usually, greater protection is carried for new parts and for production on a new line, because there will certainly be unforeseen troubles. Later on, this bank can be cut down as

[1] See also Chapter VII.

it is always easier to cut back the number of parts on hand than to increase them.[1]

Figure 75 shows a graphical aid which can be used in starting production. It gives cumulative figures for the delivery schedule called for by the customer, the schedule the manufacturer sets for himself, and the schedule for delivery

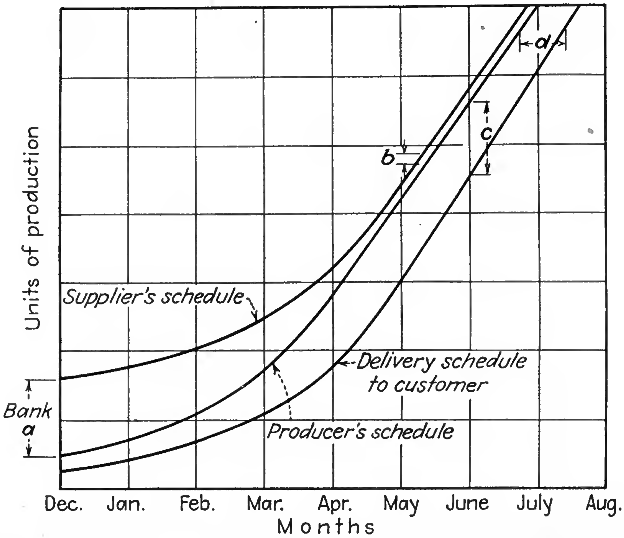



FIG. 75.—Chart showing relative schedules at the beginning of a new model.

of a certain purchased component. The bank ahead of the manufacturer's final assembly is shown by bank *a*. Actually, this includes parts in transit and in the float at the manufacturer's plant. After the rate of production becomes steady, the requirements exactly equal the production schedule. It is to be noted, however, that this bank is markedly reduced, as shown by *b*, after production is under way. On the other hand, the bank of finished units ahead of testing and delivery to the ultimate consumer, as shown by *c*, has been increased, as production expanded, to a constant amount of finished stock. The number of days' protection, however,

[1] This "larger bank" is sometimes actually smaller than that required at normal rate of production. Since the bank is based on the number of days' protection, its size varies with the rate of production.

which this finished bank represents (shown by *d*) is approximately the same in January as in July. The actual production can be posted against this curve as a means of visual control.

In the case of raw material, after the requirements have been determined, it is necessary to translate the figures into ordering units such as pounds, feet, or bars. This can usually be done by a conversion figure noted on the records of material specifications, parts record card, or similar device.

## PROCUREMENT

It is the function of the purchasing department to locate vendors who can ensure the steady and dependable flow of material required. In the selection of vendors to supply line-production plants, the integrity of the vendor and his ability to supply the correct parts when they are wanted are as significant as the price. Vendors must be able to meet the schedule set and should be able at all times to maintain deliveries. The importance of this qualification is well understood by many parts suppliers who never miss a delivery. They realize that if they fail on their schedules, future orders will almost automatically be diverted to other sources. Purchasing agents should impress vendors with this requirement; yet, since they are still responsible for locating reliable suppliers, they should also maintain an up-to-date library of vendors classified by products so that alternative sources of supply are known. A record of the service rendered by these companies in past years and of quality complaints and prices paid will prove extremely valuable. In some cases manufacturers will change their product design or material specification so as to be able to place orders with more dependable sources of supply.

**Ensuring Required Deliveries.**—In the event that a new supplier is selected, field men are often sent to examine his management and production facilities. These are not follow-up men; they are more closely related to the planning and production-engineering groups. The field men must make sure that the vendor understands the job and that his facilities can handle the work; in other ways they must see that the vendor's estimate of delivery can be realized. They may also check the vendor's sources of materials and investigate his planning department. Large producers use this type of field investigation for all new vendors to be as sure as possible that the supplier will not default at a critical time and delay the entire production program.

The vendor, if he is to tune his own schedule of delivery shipments to the program set by the manufacturer, must be notified ahead of time what, when, and how much will be called for. In addition to engineering specifications, suppliers should be given information on scheduled or anticipated requirements. Orders will therefore be placed sufficiently far ahead to enable the vendor to tool up his own production. Engineering changes and expected variations in requirements should be sent to suppliers early.

New vendors should not only be thoroughly investigated and properly informed but should be closely watched through the tooling-up and early stages of production. For example, if it appears, at the end of 3 weeks, that the vendor cannot possibly meet his first delivery due at the end of 6 weeks, it is often wise to place the order immediately with some other source of supply.

Purchasing agents frequently spread their orders for one product over two or more vendors, in the hope of protecting the plant against delays in delivery. Experience has proved that a careful selection of vendors is a more discriminating precaution. Still, it is difficult to obtain protection against fire or strike in a vendor's plant or against floods that wash out transportation lines, and split sources of supply remain one of the important methods of protecting production against material shortages.

**Flow of Material Deliveries.**—Plants operating on line production order their parts far enough ahead to enable the vendor to make required preparations. Yet, from these overall orders, the plants may request periodic deliveries at frequent intervals. The arrangement, for example, of buying

50,000 pieces to be released at the rate of 1,000 a week for 50 weeks may seem unreasonable to many suppliers when first proposed, as they are accustomed to filling specific purchase orders. Yet, once a supplier is used to feeding his material out at a rate rather than in bulk lots, he can usually set his own production to meet closely the requirements of his customer. In cases of standard mill runs, of small parts with generally accepted delivery quantities, and of pieces which should be kept together as in a single heat of metal, the manufacturer usually places an order or delivery schedule which allows the vendor to produce the parts economically, and he usually calls for deliveries less frequently and in larger amounts. Where the manufacturer has no space to hold a bank, or buffer stock, agreement can sometimes be made with suppliers to keep on hand certain minimum quantities at their plants or warehouses as a precaution against unusual hazards.

Some concerns place blanket purchase orders with vendors to meet their full requirements of any one item for a certain period (with the dates specified) at an established price per piece. The vendor is normally guaranteed a minimum amount which will be purchased and is informed of the peak production anticipated. The vendor tools up his plant and feeds the material, parts, or subassemblies to the purchasing manufacturer as requested by delivery schedules or periodic shipping releases. This type of purchasing fixes the price in advance, with the result that the manufacturer can set a sales price on his finished product without the danger of fluctuations in the cost of material and supplies. Since the price often has to be set at the time the total volume of sales is determined, this arrangement may be of considerable importance. In other cases, manufacturers buy at the going rate through periodic or irregular purchase orders. However, it is always desirable to let the supplier know in advance what is expected of him. Only in this way can he justifiably be called upon to ship parts and material at a rate synchronized with the manufacturer's schedule of requirements.

## MATERIAL FOLLOW-UP

In spite of the care used in placing purchase orders, most plants operating production lines still maintain a follow-up group, which constitutes another precaution to avoid shortages of even the most insignificant part. There may always be the

**SCHEDULE SHEET**

SCHEDULE SHEET NO. *13697*

SUPERSEDES SCHEDULE SHEET NO. *13610*
DATED *November 19, 1943*

| PART NO. | DESCRIPTION | DATE |
|---|---|---|
| *74-620* | *Switch for cut out* | *December 17, 1943* |

PURCHASE ORDER NO. *MA-6482*
TOTAL ORDERED *12,000*
TOTAL SHIPPED *7,000*
LAST SHIPMENT CONSIDERED: DATE *December 17* QUANTITY *500*
BALANCE DUE *5,000*

From This Balance Please Ship as Follows:

| REMARKS | DATE | QUANTITY | ACCUM. TOTAL THIS SHEET |
|---|---|---|---|
| | *December 24* | *500* | *500* |
| | *December 31* | *500* | *1000* |
| | *January 7* | *500* | *1500* |
| | *January 14* | *500* | *2000* |

Total Quantity Scheduled for Delivery this Order *9000*

SHIP TO *Borealis Electric Co.*
*Newtown, Ohio*

BUYER *C. Gooch*

VIA ROUTING *as per P.O.*

Vendor's Notice of Shipment Must be Mailed to our Purchasing Department
Same Day Shipment is made

FIG. 76.—Schedule sheet or shipping release used to instruct vendors when to ship material.

vendor who undertakes more than he can accomplish, and there may always be unavoidable delays in transportation. In most cases the follow-up clerks actually control the shipments from the vendor in that they calculate the requirements and notify the vendors of the desired delivery schedule. Schedule sheets, vendor shipping releases, or delivery instructions such as those shown in Fig. 76 may be used to inform vendors. It is through these instructions that a regulated flow of material into the plant is accomplished when delivery requirements are not specified in the purchase order.

Traffic routings are cared for when the original purchase order is placed. Rail sidings and truck-delivery space must, of course, be adequate; arrangements with the common carriers should ensure that the specified frequency of delivery can be maintained.

The work of the follow-up clerks in controlling incoming parts and material generally takes the form of a constant check of receipts against requirements. For organization, all of the purchased items are divided into groups, each group of parts being assigned to a follow-up clerk as his specific responsibility. His file is arranged by part numbers, and he keeps a record of all shipping instructions, shipments made by vendors, shipments received, or any promises made. Records should also be kept of scrap, shrinkage, or returned material; for these losses are to be incorporated in the delivery instructions when next sent to the vendor.

Whether follow-up is a function of the purchasing department or the planning department is not important. Generally, where there is a centralized purchasing department with decentralized planning departments in each of a number of plants, the materials follow-up group will be located under the various planning departments. In other cases the buyers provide their own follow-up. However, it is important that through the work of these men the material is fed into the plant uniformly, and delays in vendor shipment are noticed before they become serious. True control rests here. The requirements are figured from the production schedule, and the follow-up clerk constantly checks to see that receipts are greater than requirements. In this method comparisons are always made in terms of cumulative figures. A simple comparison between the total production requirements and the total amount of the item received amounts to a complete inventory of the component. Expressed in another way, subtraction of the parts required for production, as of any particular date, from the latest cumulative receipts gives the balance on hand in the plant. Physical inventories can be taken to check the follow-up clerk's figures, especially when closing down a line. The detailed example worked out in Fig. 77 shows a very successful materials-control system used to cover parts for both functional departments and production lines.

| STATION NO. 14 | | | | |
|---|---|---|---|---|
| PART NO. | PART NAME | USAGE | BANK REQ'D. | LOCATION ON RACK |
| 618941 | Wiring harness | 1 | 30 | R. Top |
| 641382 | Wiring harness | 2 | 60 | L. Top |
| 581616 | Instrument panel | 1 | 15 | R. 1 A |
| 580413 | Battery box | 1 | 30 | R. 1 B |
| 580414 | Bracket | 2 | 60 | L. 1 A |
| 580416 | Bracket | 2 | 60 | L. 1 B |
| 632910 | Fire Extinguisher | 1 | 15 | R. 2 A |
| 591724 | Valve | 2 | 30 | R. 2 B |
| 580410 | Battery | 1 | 15 | R. & L. 3 |
| | | | | |
| | | | | |

FIG. 78.—Rack tag used to locate and identify parts stored along an assembly line.

**Shortages.**—Another device is the use of stock checkers and shortage reports. These checkers are responsible for certain materials or certain geographical areas of the plant or line. Each day they check the stock to see that the proper bank is maintained. For every fabrication line there should be a normal amount ahead of production, while along assembly lines banks of stock must be adequate. A minimum bank is specified for each item. Rack tags similar to that in Fig. 78 will be of particular help. When the checkers find any stock below the minimum, they report it. The checkers' reports are daily translated into a shortage report such as Fig. 79 shows. There may still be ample parts with which to operate, perhaps for several days, but the parts are listed on the shortage report as notification that there is insufficient protection in the bank. These reports are sent to the follow-up clerks so that they can immediately trace the reason why any purchased part should fall below the minimum bank and can make arrangements with vendors or carriers to bring it up to normal. In the case of small standard parts, the checker notifies the small-parts storage crib to have the bank at the line replenished.

Some materials-control executives maintain a minimum of protection by carrying reduced banks and, when any delay occurs, use sensational methods to obtain parts in a hurry.

* Newly Reported Today

October 27/43
Page #2

LIBERTY PRODUCTS CORPORATION
DAILY SHORTAGE REPORT

| FOLLOW UP FILE | PART NO. | PART NAME | USAGE | | AMOUNT RECEIVED | AMOUNT ON HAND | VENDOR | REMARKS & PROMISES | DATE 1st REPORTED |
|---|---|---|---|---|---|---|---|---|---|
| | | | AMT. | MODEL | | | | | |
| ASSEMBLY STATION 3 CONT. | | | | | | | | | |
| 3 | BAC12ER | Bolt 3/4x7x2½ | 2 | all | | 0 | Buffalo Bolt | Picking up 2000 10/26 | 10/24 |
| 6 | C-126472 | Cross Shaft | 1 | all | 640 | 1390 | Highland | More tonight | 10/20 |
| ASSEMBLY STATION 4 | | | | | | | | | |
| 4 | * 616792 | Mounting Bracket | 2 | T,W,M | 470 | 470 | Grand River | | 10/27 |
| 8 | A-294628 | Light Ass'y | 1 | T,A | 60 | 58 | Long Bros. | Will ship 120 today | 10/22 |
| ASSEMBLY STATION 5 | | | | | | | | | |
| 1 | * 164821 | Gas Line | 1 | all | 500 | 1800 | Thompson Tube | More on 10/29 | 10/27 |

Fig. 79.

Telephone calls round the country, special automobile pickups, or expressing of parts by air in order to keep the line running may be necessary when shortages are threatened. These methods should be looked upon as a failure of someone to do his job and should be minimized as far as is consistent with the cost of protective banks and clerical work.

During times of scarcity the necessity of expediting material from vendors' plants into the manufacturer's shop is greatly increased. Even in normal times many of the high-production shops maintain field men to trace late deliveries or misplaced shipments. The maintenance of field expediters working out of the purchasing or the materials-control department has justified its value to many companies, particularly where it saves shutting down production lines. Short-term expediting is largely on a personality basis. True expediting is not done from this point of view; it is more a matter of planning—of carefully weighing the in-process, storage and transportation times, the necessary banks, and the dependability of vendors' shipping promises. Successful expediting should correct failures in planning and may even take the form of instructing suppliers in better planning methods.

## INTRAFACTORY HANDLING

Another aspect of materials control is the proper movement of material within the plant. The handling and storing of material should be accomplished in such a way as best to facilitate production; material must constantly be available at the point of usage so that interruptions or delays do not occur. Since the materials-handling group is normally a nonproductive, or overhead, department, with more or less fixed expenses, it behooves the operating manager to make sure that his direct-labor workmen are adequately served with material.

The control of material within the plant consists of receiving material, distributing it to the fabricating or assembly departments, moving it from one department to another, storing it in rough or finished state, and shipping. These functions are often headed by a materials supervisor who is frequently responsible to either the planning or the production superintendent.

**Receiving and Shipping.**—The receiving function differs very little in line production from that in job-lot manufacture. Deliveries will be more frequent, and parts are likely to be delivered directly to the point of usage or near the head of the various production lines rather than to any one central receiving point. This makes a more difficult problem of supervision over the separate receiving areas but saves the time and effort of rehandling the parts from a central receiving point. It is wise to have the traffic department tie in closely with the receiving of material. For example, where parts are received by rail, the sequence of cars can be determined so that each car can be spotted at the most accessible point for delivery of its material to the proper production line. This may be accomplished by having sent to the receiving department or materials-control group a report of the cars in the freight yard ready for transfer to the company siding. The same holds for shipments received by truck. Incoming deliveries should be made at the proper receiving area, and often the contents of the truck can be loaded in such a way that the sequence of parts is prearranged for systematic unloading.

After the material has come through receiving inspection, most line-production plants will move it directly to the point of usage if this is at all possible. Likewise, when moving parts in process from one department to another, every effort is made to move material directly and without interim storage. Sometimes conveyors can be used to synchronize the receiving room or production department with the flow in succeeding lines, so that the presence of a representative of the materials-handling division is unnecessary.

The shipping of goods from production lines is more regular than from job-lot plants; shipments can be closely coordinated with the more uniform production schedules. Because of this, many factories require little more room at the end of their lines than is sufficient to store a few days' output of finished units.

**Handling between Lines.**—While the movement of material to and from lines is the responsibility of a materials supervisor, the receiving and shipping departments and the stock checkers may also come under his direction. Certainly, the handlers and move men will; the former actually do the loading and unloading of conveyors, skids, and trucks, and the latter transport the material after it is loaded. Materials foremen or dispatchers supervise the work of these employees. Their actions are tied in closely with the stock-checking function.

When a dispatcher begins work on a new line or has been recently transferred, dispatching cards with instructions are issued for the various parts to be moved by him. Although the maze of conveyors and storage areas in many line-production plants appears complicated, there are generally fixed assignments for the handling of material so that as soon as production gets under way, the men become familiar with the parts, and the problem is little more than handling to conform with production schedules.

In practice, this handling proceeds smoothly. One can stand at the end of a line and watch the banks dwindle down to 12, 10, 8, 6; and, as these last few pieces are being used, the trucker arrives with the next skid of parts. Should the trucker fail to appear, it is likely that a stock man or checker would be on the spot with two or three parts under his arm. It is his responsibility to serve production by keeping adequate material in its proper place at the line. On the line itself the handling of material will be under the control of the production supervisor or the operators themselves.

## STORING

In line-production plants, there are very few central storage cribs. The tendency to store parts in immediate proximity to the line rather than to issue them in driblets from a storage area has already been mentioned. Material may be held at the receiving room or banked at the production line; and, so far as possible, there should be direct transport between these two points to eliminate extra handling. Such an arrangement makes material more accessible to production men and obviates the use of requisitions. It has, on the other hand, the disadvantage of lacking enclosure.

With parts stored along the lines, there is simplification of inventory recording; no record is kept of disbursements, appropriated portions, or balances on hand. No such perpetual inventory records need be maintained, for if material follow-up operates properly, it will always keep deliveries ahead of requirements. It is true that great reliance must be placed upon the stock checkers, who should be maintained for line production. The insurance which they provide could not be replaced by either central storage cribs or perpetual inventory records.

**Storing on the Line.**—On the production line itself, parts can be stored at several places. A bank is always held at the head of the line. Even though the stock is fed individually to

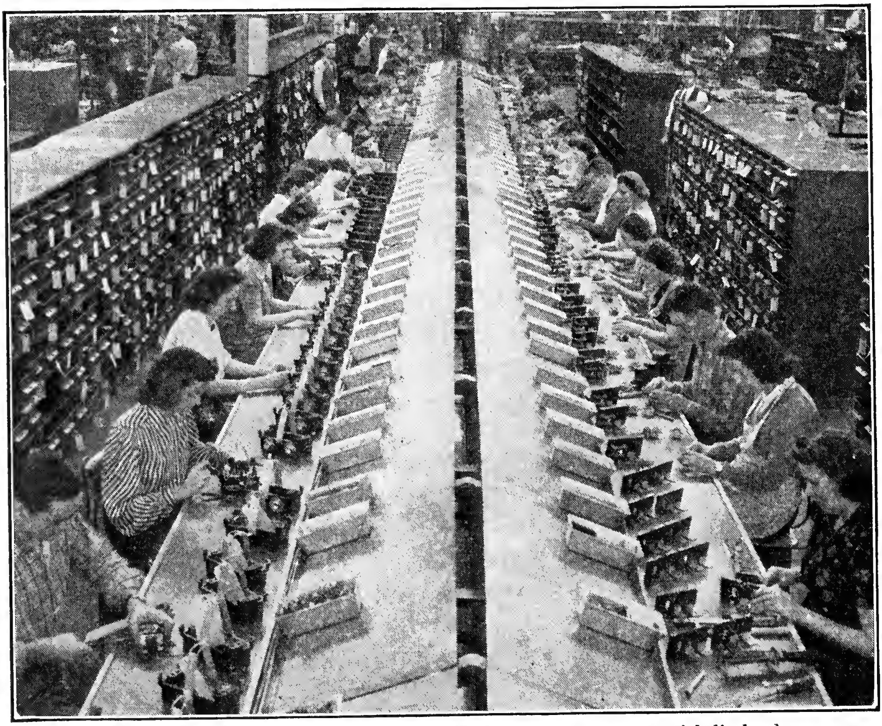


FIG. 80.—This line can be used to produce a variety of products with little changeover. Here it is set up to make electrical control units. Stock is stored temporarily in front of each operator. The open bins behind each work station hold larger stocks of parts. Bins like these may be filled from either side of the bin racks.

the first operation at the rate of one per cycle, some safety bank should be maintained. If this is a dead bank, the material will have to be turned over periodically in order to avoid deterioration. The circulation of material in such a bank is usually more automatic than in job-lot manufacture. Safety banks are frequently held in the lines themselves, arranged either to permit the main flow of material to pass or to serve as a live bank.

In assembly work, most of the material is stored at the various stations along the line. It may be placed beside the operators, directly on the workbench, or in bins adjacent to the line, as in Fig. 80. Such bins and storage areas are replenished by the stock men who are instructed to keep them filled with enough material to supply the line for a stated period. These bins or trays are sometimes replenished hourly; in most cases, less frequently. Much of the moving of large stock is done at night to avoid interference with production workers or to prevent congestion of the work areas.

Material is often stored on a conveyor or rack of some kind between the end of a feeding subassembly line and the assembly line which it is supplying. When these parts are scheduled to the line, their sequence will be maintained. Small parts are often stored in racks overhead or across the conveyor belt from the operator. They may even be delivered to such racks from the receiving department and each day disbursed to smaller trays in the immediate working area. Sometimes all parts for one assembly are stored at the head of the line and placed in one container. In one hat company the felt body, leather, band, and other trimmings are all placed in one tray. As it is slid down the line, each operator has all the necessary material before her.

In one plant assembling a variety of different electric motors, the storage area still paralleled the line but was not specifically at the point of usage. Actually, a row of storage bins and racks stretched along the entire assembly line, dividing the shop into two parts. Fabrication and subassembly were performed on one side and the parts fed through the storage racks to the assembly operations. This type of storage area is quite common where fabrication or subassembly is done in job lots.

**Storing Near the Line.**—Material is sometimes stored at the end of the line as a bank ahead of testing, repair, touch-up, or packing. Generally, the bank at the end of the line is held only until enough parts accumulate to make an economical shipment to the customer or warehouse.

Parts can also be stored on conveyors delivering to the line. These conveyors may circulate throughout the plant or at least between the production line and the receiving area, fabrication department, or storage bank. If this conveyor is lengthy, a sizable float will be in transit. When it is desirable to carry a larger amount, more hooks are filled on the conveyor. Where parts are banked and not moving, they are frequently left on their hangers on a conveyor siding. In this manner, many storage banks of parts and subassemblies are maintained off the floor and can be slid onto the delivery conveyor with a minimum of handling.

**Identification of Parts.**—The storage of parts along the line demands that they be clearly identified. Misuse of similar but different parts is likely to occur when one of the parts is short. Checking such misuse usually depends on the departmental inspector.

When the misuse of parts is discovered, special inventories may assist in finding out why certain parts are short. Such disclosures may lead to an investigation by the engineering department and may result in change orders. On the other hand, it may be necessary to instruct production in the correct use of the parts. When the operator is familiar with the job and the parts are located conveniently, it becomes easy to use correct parts. There is sometimes the alternative of removing the source of confusion by separating the stations at which similar parts are used.

**Storing Away from the Line.**—It is not always practical to store parts at the line. With large incoming shipments or bulky goods there is rarely room near the line to maintain capacious banks. Here it is frequently possible to maintain banks at some distance and to feed parts on a delivery conveyor. As seen above, small standard parts which cannot be procured in small quantities, or which are used in different places in the plant, are generally put into a standard-parts storage area and issued periodically to the production lines. Under other circumstances raw material must be held in a storage area pending the scheduling of economical fabrication runs. Here the material cannot be stored at the point of usage, for the machine will be used for producing many other parts. When the fabricating department, operating on the basis of lots, precedes a production line, the bank will frequently be held in the fabrication shop rather than at the line. Moreover, subassemblies and parts are sometimes stored in sets. When ready to be installed, the complete set, including all the necessary components for one particular operation, can be moved to the line. This is not unlike the hat line where all parts for one unit are placed together and assembled at different points as they all move along the line.

To satisfy a customer who owns the material, it may be necessary to maintain enclosed storage areas for such stock. Certain parts particularly subject to pilferage also are kept in enclosed centralized storage cribs and distributed at frequent intervals to the line. In the case of spark plugs and windshield wipers, automobile companies have found little difficulty if they hold one man responsible for installing them and give him locked-bin facilities. Larger parts, such as switches, and fragile parts, such as lamp bulbs, are kept in a storeroom and issued periodically directly to the production worker responsible for the installation. Material which may spoil easily or endanger workers is seldom held at the line in large amounts. Where the conventional type of storeroom is used, adequate delivery to the line should, of course, be provided.

## EXECUTIVE READING

"Synchronizing Materials to the Assembly Line Demands Exacting Attention," *Automotive Industries*, Vol. 63, No. 14, p. 482. Article by Joseph Geschelin.

"Coordinating Material with Production Needs," *Bulletin* of the National Association of Cost Accountants, Vol. xxiii, No. 11, p. 793. H. J. Myers states the fundamentals of material control, together with the details.

"Time in Process," *Advanced Management*, Vol. 5, No. 1, p. 11. Article by Franklin G. Moore.

"When Others Take a Licking on Their Surplus Stocks," *Factory Management and Maintenance*, Vol. 97, No. 5, p. 51. Eugene F. McDonald, president of the Zenith Radio Corporation of Chicago, explains inventory control in radio production, stressing the importance of sales forecasting in order to keep inventories at a minimum.

"Determination of Minimum-cost Purchase Quantities," *Transactions* of the American Society of Mechanical Engineers, Vol. 50, No. 10, p. 41. Article by R. C. Davis.

"Production Control," American Management Association, M.P.1, 1932. C. L. Schweitzer gives the details of control over the high-volume items at the National Cash Register Company.

# CHAPTER XI

## PRODUCTION CONTROL

Production control means literally the planning, scheduling, dispatching, and expediting of machines, materials, and men within the plant. Because the term has acquired a semi-technical meaning, many industrialists regard production control as something highly complicated and mysterious. This is not the case. Production control is simply the application of common sense to the problem of maintaining economical and efficient processing.

### EASE OF CONTROL IN LINE PRODUCTION

If the arrangement of equipment disregards progressive flow, material is moved with difficulty and must be accompanied by move tickets and identification tags. The multiproduct plant, with variation in designs and lack of a production forecast, must face the problem of varying lot sizes and irregular schedules. Nonstandardized parts mean that shop orders must be written in detail and every order individually routed. Operators are assigned to whatever job the foreman decides to run. Operating times, on which schedules must rely, are often mere guesses and progress follow-up is often unorganized.

In line production this situation is hardly possible. Routing the work—determining the path it will follow—customarily involves the sequence of operations, the proper tools and fixtures, selection of the most economical machine, the availability of machines, and the economical lot size in which the product may be routed. In the production-line layout, this routing is worked out and established when the line is set up. Arrangements are made to have the work performed at specified stations so that the production-control group need not concern themselves with selecting the workplace for each operation in each order. They need not schedule each operation or machine, for the line will be scheduled as a unit. It is

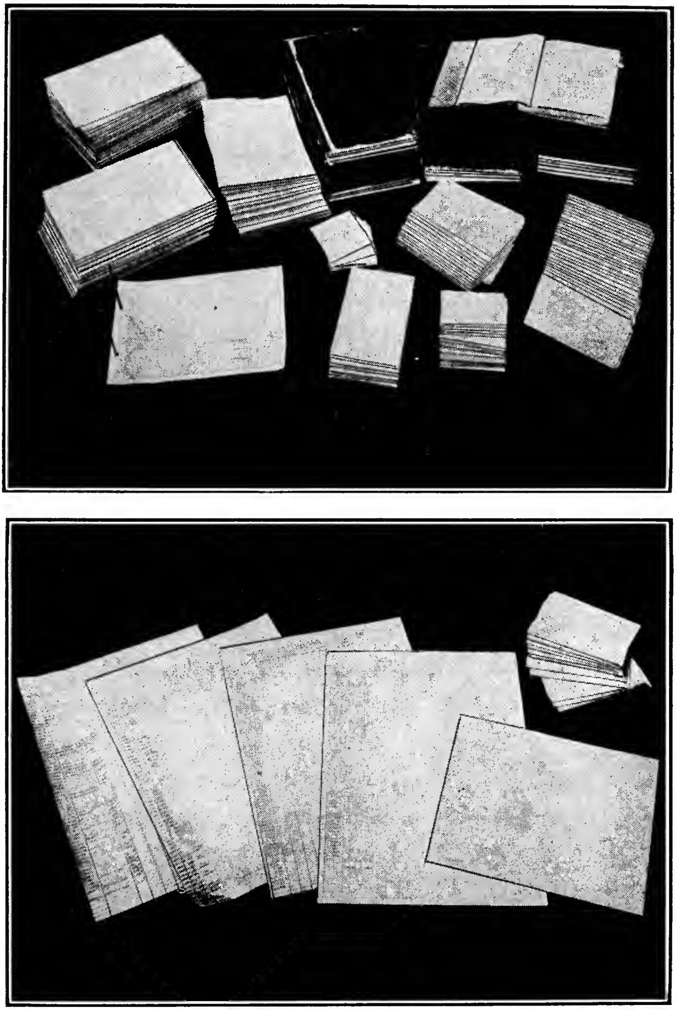


Fig. 81.—Sets of manufacturing records were reduced from 13 to 6 and the number of records kept was cut from 4,900 to 250 annually under the straight-line method. (*Courtesy of Alexander Hamilton Institute.*)

next to impossible for material to be misplaced or lost, so that the necessity for following up material in process between operations is practically eliminated. Control over tools will be simplified, for they will always be delivered to the same machines or work areas.

Dispatching of work orders is greatly reduced and move orders or forwarding tickets are not required except occasionally at the end of the line or between lines. The line as a whole will be notified of its schedule which, in most cases, is the same as the day or the week before. Moreover, since there is a steady rate of flow which almost guarantees a uniform daily output and a constant float in the line, little check in process is necessary. The scheduling group need only notify the line of its schedule and be sure of sufficient material on hand at the line. Daily check of the output coming off each major line will be made, for delays must be offset quickly by overtime or schedule revisions. As a result, a simple and direct system of control is possible. Figure 81 shows an actual comparison of the paper work required for production control for functional and line production.

## LINE SCHEDULING

As in the control of incoming material, so the production of parts and subassemblies in the various departments of the plant will be scheduled to keep pace with each final line. The rate of the final line is determined by the production schedule established. The monthly production schedules are broken down into weekly and daily requirements. The various stages of material in process are traced backward, and an allowance is made so that each line in the plant can be scheduled. This coordinating of the different fabrication and subassembly lines with the schedule of finished units allows the material to flow through the plant at the optimum speed. Figure 82 represents a typical schedule breakdown.

In line production, the production-control office should have authority over the shop as far as schedules are concerned. Delay of succeeding lines for lack of fabricated parts or subassemblies cannot be tolerated, for no other work can be run in the idle machines or over the idle assembly line. Foremen must produce what the production-control office specifies, since banks and floats are usually small. The production superintendent may appeal to have the schedule changed, but until it is changed, he is responsible for meeting the schedule as set.

Each line in the shop is designed to handle an expected peak rate of production. Schedules vary, and therefore the line may be called upon to operate efficiently at rates well under maximum capacity. Changes in schedule, while upsetting to balance, can actually be accommodated more easily

PRODUCTION SCHEDULE

Model No. XL-2 Revised Oct. 1, 1943

| MONTH | SHIPPING SCHEDULE | | SERVICE PARTS | | WORKING DAYS | DAILY SCHEDULE |
|---|---|---|---|---|---|---|
| | Month | Accum. | Month | Accum. | | |
| Through Sept. 43 | | 300 | | 60 | | |
| Oct. | 120 | 420 | 15 | 75 | 26 | 5.2 |
| Nov. | 160 | 580 | 20 | 95 | 25 | 7.2 |
| Dec. | 240 | 820 | 25 | 120 | 27 | 9.8 |
| | | | | | | |

FIG. 82.—Breakdown of monthly schedule to indicate daily production schedule. Assuming there are normally 50 units in the assembly system—10 as a bank, 30 on the line, and 10 ahead of test and shipping—fabricating and subassembly must work about 10 days (50 ÷ 5.2) ahead of the shipping schedule during October. The number of units on the line generally remains the same, but to maintain a 2-day bank ahead of assembly the feeding lines should reach the 7.2 rate by Oct. 29. Likewise, other departments or suppliers must build up their production or banks far enough ahead to supply these feeding lines.

than in a job-order shop. Since the line acts as a unit, any change in the rate of production will be felt evenly throughout its length. Extra men may be put into the line, but as they will all be within one department, such adjustments can readily be made. Yet, because of the dependence of the line on feeding departments, alterations in schedules should be made gradually with notification far enough in advance for fabrication and subassembly to get parts to the line. Foresight in planning and checking rates of production is vital. For example, if a plant is operating 25 days a month and making four units per day, and by the twentieth day it has shipped 80 per cent (80 units) of its monthly schedule, it cannot increase its monthly output 50 per cent (to 150 units) at such a late date. By tripling the rate of production, only 60 units can be made in the last 5 days, for a monthly ouput of 140.

## CYCLING

Although we have spoken only of controlling production lines, it must be recognized that back of these lines lie many fabrication and subassembly operations that cannot economically be introduced into the line itself. Punch-press and screw-machine operations are generally much faster than the established rate of assembly. These machines may be set up to run off a month's supply in a few days or even hours. The light-chemical and food industries commonly make large batches of material from which are released amounts sufficient to keep the packaging lines busy. Such operations are grouped in functional or process departments and scheduled to coordinate with the final line.

This is essentially a situation of producing to stock. The parts can be made up and stored until the piecemeal disbursements to the line reduce them to an amount where the stock must be replenished. Control may be by means of inventory records and maximum-minimum stock limits, schedule requirements, stock checkers, or some other controlling device.

One of the methods of controlling these functional, batch-process, or miscellaneous machining departments is known as *cycling*. The term *cycle* here applies to a complete rotation through one machine of all the different items that are to be fabricated by it.[1] The cycling time is the number of days allowed for one cycle, or the time taken in the production line to use up one batch, lot, or bank of any one part made by the machine being cycled.

The procedure of cycling is charted in Fig. 83. Here the four parts shown are produced by a certain machine operating on a 30-day cycle. In order to keep in schedule with the

[1] This should not be confused with the cycle time or worker's cycle of operations which he performs on each piece as discussed in Chapter VII; still this same cycling idea is applied in the line when banks are periodically built up and reduced.

assembly line which it is feeding, when the machine is set up and run, a sufficient quantity of each part must be made to supply the assembly line for 30 days. Thus in the middle of the seventh week, the machine is set up for part No. 2, and enough parts are made to last until part No. 2 can again be run. A safety bank is usually maintained to ensure line

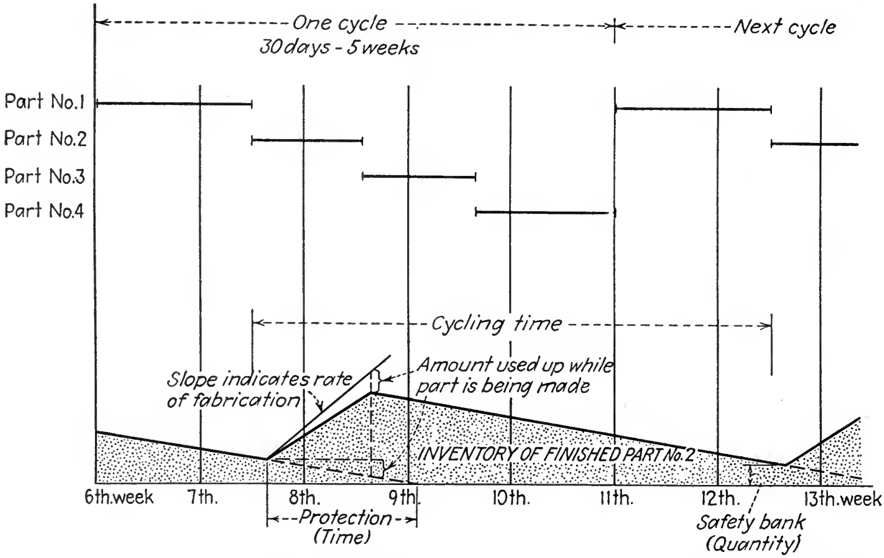



FIG. 83.—This shows the method of cycling one machine which can operate faster than the required rate of production. This represents a fairly "loose" cycle with ample safety bank of 8 days' protection. Production figures are here posted at the end of each day. Shaded section shows finished inventory of part No. 2. Bars indicate machine time allotted to each part.

operation in case of breakdown or an unusually large demand for parts.

Sometimes the cycling of miscellaneous job-lot departments is left entirely to the foreman. As his problem is to meet the daily requirements of the lines he is feeding, he must protect himself with banks of sufficient size. Where the size of the bank is important, where it is difficult for the foreman to schedule, or where he prefers the easy jobs with long runs and short setups, it is customary for the production-control group to schedule the department. A schedule based on proper machine cycles similar to that in Fig. 84 may be issued

**DEPT. 92 SMALL PRESS DEPT.**
**SCHEDULE FOR WEEK OF 9/7/42**

As of 7 A.M. 9/4/42

DO NOT OVERRUN ANY OF THESE ITEMS WITHOUT O.K. FROM PRODUCTION CONTROL

| PART NO. | NAME | ON HAND | WEEKLY REQUIREMENTS | OPEN IN SHOP | FRI 9/4 | MON 9/7 | TUES 9/8 | WED 9/9 | THUR 9/10 | SHIP TO |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | RUNS TO BE FINISHED | | | | | | |
| 612036 | Cover | 2 000 | 3 500 | 28 000 | | | | | | Dept. 14-A |
| 624961 | Shim .020 | - | 2 200 | 9 000 | | | | | | Dept. 15 |
| 742681 | Retainer | - | - | 25 000 | | | | | | Dept. 15 |
| 794436 | Washer | 12 000 | 31 000 | 250 000 | | | | | | Dept. 15 |
| 795624 | Spring | 1 000 | 2 000 | 8 000 | | | | | | Dept. 12 & 20 |
| | | | | SCHEDULED FOR MONDAY 9/7 | | | | | | |
| 614207 | Plate | 0 | 1 000 | 5 000 | | | | | | Dept. 14-B |
| 894761 | Clip | New Job | | 50 | | | | | | Dept. 62 |
| 962143 | Handle | 800 | 800 | 3 200 | | | | | | Dept. 14-A |
| 962153 | Guide | 600 | 2 800 | 23 500 | | | | | | Dept. 15 |

FIG. 84.—Schedule for punch-press department operating on 4- and 8-week cycles. Figures for the quantity on hand may be obtained from weekly inventory by stock men, perpetual inventory records or from calculations of usage based on production schedule, scrap reports, spare parts shipments, etc. The amount for which raw stock requisitions have already been made out (minus amount already run) is shown as "open in shop." This is the actual schedule of what to run, though machines in which it is to be run are determined by the records in the shop. The daily record of actual production is posted in the adjoining columns. In the figures given, note the following for each part—*cover*, Less than 3 days' bank on hand; want job run right away; 8 weeks' requirements to be made. *shim*, No "on hand" figure; this part being made on 4-week cycle, a little over 4 weeks' requirements are scheduled. *retainer*, A special order to be sent to general stores; will not be cycled; will run on spare machine. *washer*, Two days' supply on hand; on an 8-week cycle. *plate*, None on hand, but this is a new plate; 4-week cycle will be used with a 1-week bank (4000 + 1000 = 5000).

periodically to the shop. A series of machines or a complete production line may be cycled as a unit in this same way.

Many considerations similar to those used in determining economical lot sizes are important in deciding how frequently a part should be cycled. The quantity desired, the cost of the setup, the storage space and containers required, the value of the parts and their susceptibility to obsolescence should all be considered. It is important to note that the cycling times

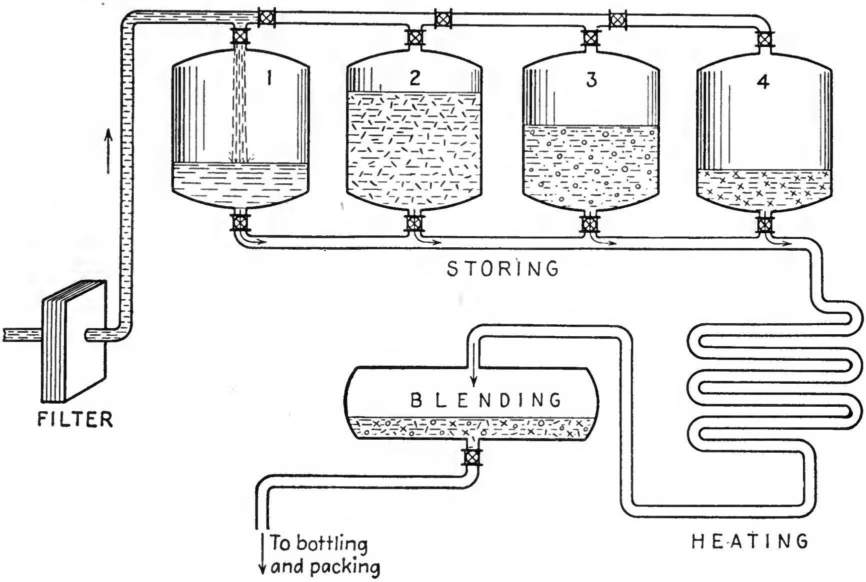



FIG. 85.—Use of storage tanks to accommodate batch cycling of the producing facilities. When tank 1 is filled, production will be changed to make an economical run of tank 4 ingredient.

are shorter when a new job is getting started. Only in this way is there an opportunity to produce all parts. Early design changes also make this a prudent arrangement.

A similar procedure is followed in the chemical industry when batch production is used. As Fig. 85 shows, batches can be made up on a systematic cycle planned on sales estimates. Thereafter, the storage or blending tanks can be drawn upon continually to supply immediate shipments.

## FABRICATING-LINE CONTROL

The control over fabrication lines is surprisingly simple. Material must be delivered at the head of the line in quantities that will keep the line operating. This is the responsibility of the materials-handling crew. The materials dispatcher or foreman can generally determine from the production schedule the quantities and frequency of delivery needed at the line. In other cases he is given instructions by the production-control group or develops a material-delivery schedule with the production foreman on the line.

When the material reaches the end of the line, a check is made of the number of good pieces. Some form of forwarding tag, inspector's report, or bonus ticket is made out. It may become a basis for sending the work to the next department or for determining the workers' pay. However, from the standpoint of control, this verification informs the production-control office if the schedule is being properly met. Frequently, there are check points in the middle of the line, but production control is interested primarily when material leaves one department for another and needs to verify interim progress only on lengthy lines where delays may not be easily noted. By posting the figures of the daily departmental output, the shop-schedules clerk can follow up each item. When there is a delay, he knows where the trouble lies without tracing the material through several departments. If the number of in-process expediters in the shop is any measure of the effectiveness of production control, line-production control is superior to job-lot procedure.

Where like parts demand different operations on the same line, specifications or instruction papers may go along with the work. Spray painting, for example, is sometimes done in lots, but it is often easier to identify each piece and paint according to the color called for merely by changing guns as each part passes. Parts that are made to nonstandard dimensions are often accompanied by a print or instruction sheet.

## ASSEMBLY-LINE CONTROL

Once an assembly line has been set up to handle the desired rate of flow, the control of production is chiefly a matter of feeding parts and subassemblies to the various work areas at the rate and time required. The delivery of parts and subassemblies should be synchronized with the speed of the assembly line if interruptions are to be avoided and a minimum float held in the plant.

The guaranteeing of material at the line when needed may be accomplished by two methods. First is the maintenance of stock banks along the line to be replenished on an economical basis. This is perhaps the easiest and most common method and has been previously discussed in Chapter X. The second method is the use of delivery conveyors or feeding lines.

Continuously circulating conveyors may be of several types varying from a few feet to several hundred yards in length. Ordinarily, they are set up to hold a number of parts and to circulate at a rate fast enough so that the operators need not wait for stock. Actually, the workman takes off only as much as he requires and lets the rest go by, but there is always a supply of stock within reach. Handlers in the stock room or at the receiving dock keep replenishing emptied hooks or carriers.

Automatically indexing conveyors of the endless variety accomplish the same end. They are set to feed material at a rate faster than the speed of the assembly line. The conveyor stops itself by some automatic control, such as a limit switch or electric eye, when the stock is carried into the desired position. After the worker removes the piece, the conveyor again indexes itself.

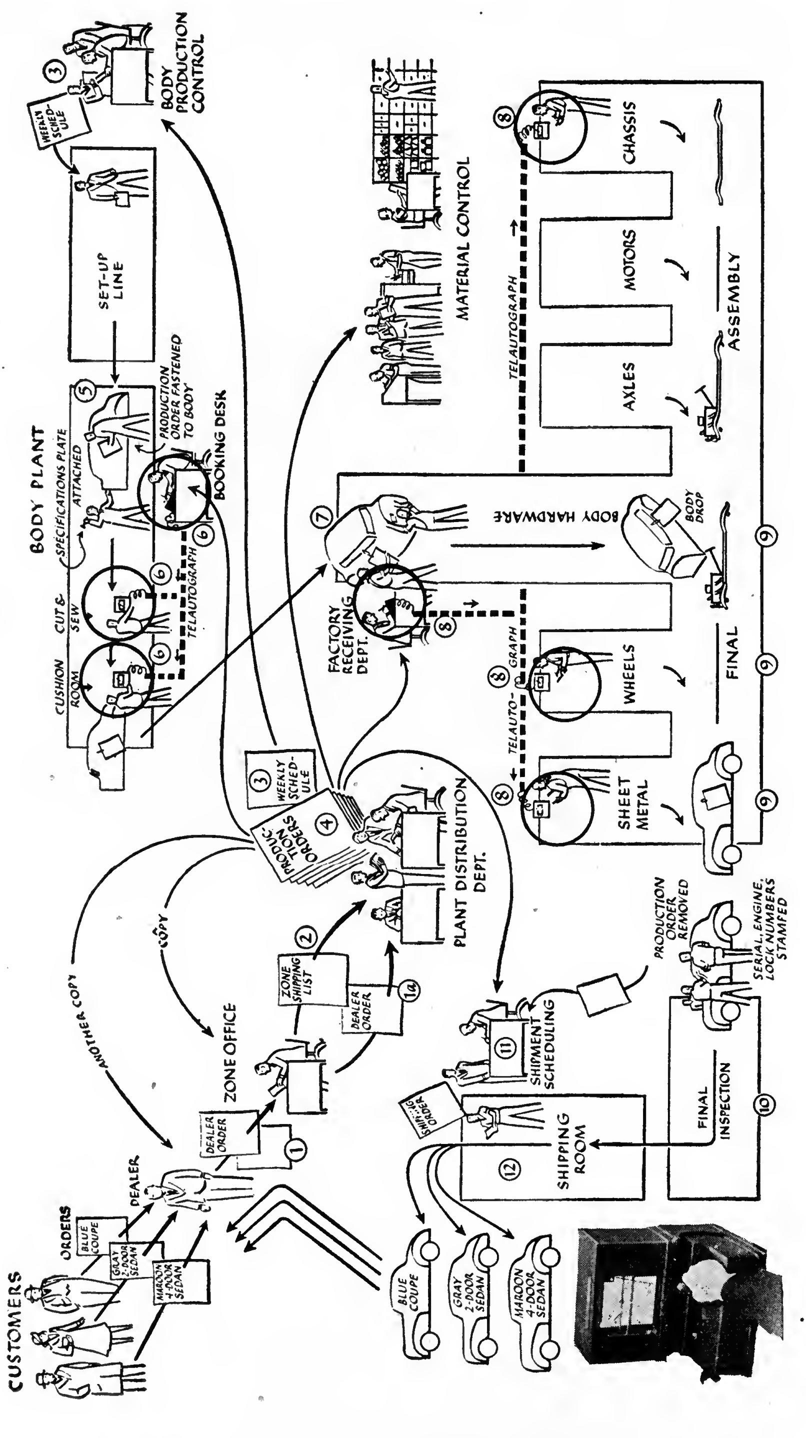
Feeder lines and delivery conveyors may be scheduled to the assembly line by adjustment of the speeds of the two. For a true scheduling of parts, it is necessary to determine the time interval required between the subassembly line or conveyor loading point and the point of usage. Once this time relationship is worked out, loading of the parts in correct sequence is the only problem. A variety of parts or colors or models can be scheduled over the same conveyor or subassembly line so long as the order of loading is the same as the sequence of parts on the assembly line which they are to join. This is standard practice in automobile-assembly plants.

As an example, assume that the conveyor loading station for fenders is 100 conveyor hooks from the final line. The spacing of the hooks and the speed of the conveyor are known, so the time between the loading and the removing of the fender can be determined. It is then necessary to "float the conveyor" with parts in sequence to match the cars already on the final line; that is, the scheduled conveyor must be loaded with parts to meet the No. 1 job, No. 2, No. 3, and so on along

FIG. 86.—At the control booth in a truck-assembly plant the operator is seen sorting the order cards and dispatching, via teletypewriter, the assembly building sequence to various stations along the final and subassembly lines. (*Courtesy of Dodge Division, Chrysler Corporation.*)

the line. The exact sequence of fenders called for by the car-building schedule will be supplied in advance to the stock men who do the loading.

As a further illustration, assume that at the beginning of a work period the line and conveyor get under way simultaneously. The stock handler knows that the last piece he put on the conveyor at the close of the preceding work period was for the finished unit No. 12,696. He therefore starts filling the conveyor with parts to be assembled for finished job No.


CUSTOMERS
ORDERS
BLUE COUPE
GRAY 2-DOOR SEDAN
MAROON 4-DOOR SEDAN
DEALER
DEALER ORDER
ZONE OFFICE
ANOTHER COPY
COPY
ZONE SHIPPING LIST
DEALER ORDER
PRODUCTION ORDERS
WEEKLY SCHEDULE
PLANT DISTRIBUTION DEPT.
BODY PLANT
CUSHION ROOM
CUT & SEW
SPECIFICATIONS PLATE ATTACHED
PRODUCTION ORDER FASTENED TO BODY
BOOKING DESK
TELAUTOGRAPH
SET-UP LINE
WEEKLY SCHEDULE
BODY PRODUCTION CONTROL
MATERIAL CONTROL
FACTORY RECEIVING DEPT.
BODY HARDWARE
BODY DROP
SHEET METAL
WHEELS
AXLES
MOTORS
CHASSIS
FINAL
ASSEMBLY
TELAUTOGRAPH
PRODUCTION ORDER REMOVED
SERIAL, ENGINE, LOCK NUMBERS STAMPED
SHIPMENT SCHEDULING
SHIPPING ORDER
SHIPPING ROOM
FINAL INSPECTION

The story begins with the dealer, who places orders (1) with the zone sales office. The zone office sends these orders (1*a*) to the plant. To keep deliveries as flexible as possible, and to help salesmen meet urgent orders promptly, dealers each week may notify the zone office which of their orders, on file at the plant, customers want first.

Each zone in turn relays these dealer requests (2) to the plant Distribution Department, where these so-called Zone Shipping Lists are combined and form the basis for the plant's Weekly Production Schedule. (3) While the rate of production has been established previously as based on sales estimates, the dealers' orders determine the percentage of each model and style that will be made.

When dealers' shipping requests are received, the corresponding dealer orders are transcribed on a Production Order form (4) down to the last detail. Copies of this are sent to Material Control, the Body Booking Desk, and the Receiving and Traffic departments. At the Body Booking Desk the order enters the assembly process. Here the orders, after having been grouped according to paint, upholstery, and glass requirements, are attached to the proper bodies as these come off the body setup line (5).

From this point each body is earmarked for a particular dealer or customer. Body books, punched with the correct color and trim specifications, are attached to the body. From the Booking Desk the trim specifications are relayed ahead by means of a telautograph system (6) to Cut and Sew, the Cushion Room, and the Production Control office. This is to make sure that the right materials are available in the right order as the bodies progress along the line.

After passing through the Body Paint, Upholstery, and Glass departments the body is forwarded to the assembly plant Receiving Department, (7) with the Production Order still attached. From the standpoint of giving the customer what he wants this is a very important nerve center in the plant. Here the Production Order is examined and the exact specifications are flashed ahead over a telautograph system (8) to the Wheelroom, the Chassis line, and Sheet Metal bank. This method of written instructions enables these departments to feed the required parts, which have been made ready according to schedule, into the subassembly and final assembly lines at exactly the right time. Thus the proper chassis to match the body, the right type and color of wheels, and sheet metal, all come together (9) in accordance with exact specifications.

After passing final inspection (10) the car is ready for shipment. Under the supervision of the Traffic Department (11) the cars making up each dealer's orders are assembled (12) and started to their destination by train, boat, or truck.

Fig. 87.—Dispatching of the car-building sequence to various points along the assembly and subassembly lines is done here by means of the telautograph. The transmitting end is shown at lower left. (*Adapted from "Folks," General Motors Corporation.*)

12,697. He then continues to load fenders of the various types called for in the scheduled sequence regardless of his distance from the line.

The same sort of timing holds true in the case of subassembly lines. If the final line has been building a standard model during the morning but must shift to a special order at noon, the feeding line starts the parts moving for the special order at 11:28, or at the hour set by the time differential. Here, again, it is not necessary to know specifically when a certain job must start; the sequence of jobs ordered is the only information needed. As the feeding line is cleared of its float for one product, the workers will begin at once to put the new item over the line. Likewise, when the line is to be entirely cleared, as at the end of the day or week, the regular crew tapers off activities in order to allow the float to be used up. To "refloat" the system may require workers to come in early the next day, though delivery conveyors can be loaded quickly by increasing their speed.

If a bank or enlarged float is held between two lines, or if parts in transit have gathered dust or grit and must be rewashed near the line, these parts must continue to maintain their original sequence so long as they are scheduled to meet specific assembly units.

Any interruption in the time relationship between two synchronized lines should be quickly remedied. If the assembly line stops, any powered feeder lines or delivery conveyors must also shut down unless there is capacity for emergency storage. It is customary, therefore, where the shutdown is not automatic, to have a control switch at the end of every feeding line.

**Dispatching for Assembly Lines.**—The scheduling of the various subassembly lines and feeding conveyors must, of course, proceed from the same point that establishes the assembly schedule. From this point, notification of the assembly sequence is broadcast to each loading station which must be scheduled. Figure 86 shows such a dispatching point. This dispatching may be done by list, cards, or some communicating device such as the telautograph or teletypewriter. By these means, the color, size, finish, shape, model, or style of any part or subassembly can be selected and loaded in the proper sequence to meet the correct assembly unit, as may be seen in Fig. 87. Where the exact order of units cannot economically be predetermined, the sequence will be established when the determining item—that scheduled item which will be in the system the longest—takes its identification in sequence. In automobile manufacture this is generally at the point where the body is assigned a specific building number.

Communicating devices of all kinds may be of assistance within and without the plant. One company makes hourly long-distance telephone calls to its subassembly plants in order that numbers of subassemblies may be identified and their scheduling established at the main assembly plant. Any corrections or changes in sequence can generally be transmitted over the same communicating device.

## EXECUTIVE READING

"Production Planning in Standard Quantity Manufacture," Chapter XLIX in "Industrial Management," John Wiley & Sons, Inc., New York, 1940. Richard H. Lansburgh and William H. Spriegel are coauthors.

"Luxury Goods, Too, Must Be Closely Controlled," *Factory Management and Maintenance,* Vol. 99, No. 12, p. 73. H. F. Waterhouse, engineer with Ross, Wells and Company of New York, describes the production-control system in a cosmetics plant.

"Synchronizing Materials to the Assembly Line Demands Exacting Attention," *Automotive Industries,* Vol. 63, No. 14, p. 482. Article by J. Geschelin.

"Production Scheduling," *Production Control,* Vol. 3, General Motors Corporation, 1940. Article by the Fisher Body Council for Executive Development describes the method of scheduling automobile parts and subassemblies to the requirements of the assembly plants.

# CHAPTER XII

## QUALITY

Inspection protects company reputation and ensures assembly departments of acceptable parts. Equally important, by immediately informing production of defects, it acts as a control over processes and thus avoids useless operations on spoiled work. Quality control should be measured by the number of defects prevented rather than the number of rejects disclosed.

### JOB-LOT AND LINE INSPECTION

In line production and in job-lot production, the responsibilities of the inspection department are equally important. However, there are differences in the problems of inspection under the two methods of manufacture. Line production is generally characterized by a large and uniform output. With such volume, a great many defective pieces may be produced in a relatively short time. The faster the line, the more important becomes the maintenance of accuracy. On the other hand, defective work can seldom accumulate on production lines, for the amount of material in process between the first operator and the first point of inspection is relatively small. Consequently, the error is usually found before work has been done on very many pieces. This is not quite true where large floats of material are maintained on the line, though it certainly holds where a succeeding fixture checks the work of previous operations. Still, the reduced inventory and shorter time in process on lines as compared with job-lot production do assure quicker detection of errors and often make it possible to lessen inspection to fewer points.

In line production there is constant repetition of the same operation by each operator. As the worker's familiarity with his particular job improves, the regularity of each operation and of the product as a whole increases. This tends to make a more uniform product and reduces the probability of error. At the same time, it tends toward more uniform inaccuracy; that is, the degree of variance of the inaccuracy is lessened. If an operator's work is wrong in only one way, the trouble can be located and corrected; but if it varies in its inaccuracy, it becomes difficult to determine the cause.

Some manufacturers also point to the improved quality of products secured through line production. On analysis, however, the results are often due to reduced error through fewer machine setups, less breakage through better handling, or guaranteed inspection through mechanical transporting devices. Only indirectly can line production take credit here.

Organization for quality control in line-production plants and in those producing on a job-lot basis need not differ to any great extent. Committees, warehouse checks, or similar devices can be employed in either case. At the beginning of production on any new product or production line, the work of this quality group increases.

The position of the inspection department in the organization structure need be no different for line production. However, the organization within the inspection group itself will change to the extent that supervision is being placed over an inspection group scattered throughout the plant rather than in any centralized inspection areas.

## IMPORTANCE OF INTERCHANGEABILITY

Wherever volume and accuracy are both demanded, there must be interchangeability of parts and subassemblies and uniformity of raw materials. This is what makes possible the replacement of spare parts outside the plant. Where parts are quickly assembled on a line, we cannot see the accurate machining operations and the care that was taken to hold these parts to exact specifications so that they would relate exactly and easily to each other. On one automobile, for example, there are no less than 6,350 applications of precision gauges, and some 38,600 of these gauges are in daily use. Supporting these facilities are master gauges measuring down to one-millionth of an inch.[1]

Line assembly relies upon this interchangeability as a fundamental condition, for without it operations cannot be balanced. Lack of interchangeability of parts will affect the assembly costs under any method of manufacture. But for line assembly, as far as it is possible, any operations which will cause delays or variations in assembly time must be eliminated.

For assurance of interchangeability, operations which may introduce variance, such as the warping due to welding or springing of parts in subassembly, are, if possible, introduced early in the sequence, so that these variances may be later neutralized by subsequent operations. At one aircraft plant the importance of this principle was represented in an investment of $200,000 in one machine. Actually, it consisted of eleven more or less standard machines mounted on one large frame so that the relation of each machine to the other was fixed. Every wing section passed through this equipment, so that each had exactly the same holes located in exactly the same relationship.

Gauges, as tools of the inspector in controlling quality, in any quantity-production shop assume an importance far out of proportion to their actual cost. In the principle of quality, there is a difference between line production and job-lot manufacture. On the line the objective is to make the part meet the gauge, whereas with the job lot the idea is usually to make the piece so that it will function in a particular assembly. In the production line, the part must only meet the gauge, and it will be satisfactory for assembling without any consideration of its mating part. This means that specifications should be carefully planned and accurately designed and that gauges should be correct. In line production, where the inspector checks operations on only a few items, and where he is likely to be less skilled than the man in the job shop,

[1] Cameron, W. J., "Final Assembly," Ford Sunday Evening Hour Talk, Mar. 5, 1939.

greater emphasis should be put on the design and use of fool-proof gauges. Effort should be made in the designing of the gauge to remove the need for judgment and skill. Accurate jigs, fixtures, measuring devices, and expensive gauges pay for themselves many times over in line production when they ensure uniformity.

Line production can still be used without interchangeability of parts and subassemblies if large floats are held between operations or liberal time allowances set. Many times, the use of matched parts or selective assemblies may be advisable. The parts are graded or sorted at the time they are inspected and are assembled with other parts which have also been graded. In the case of engines, for example, after the cylinder walls are honed, they will all be within specifications, but each will perhaps vary slightly from the others. The inspector will mark the size of each cylinder; and, when it is assembled, a piston assembly, which has also been sorted out by size, will be inserted in the proper cylinder. Here is an instance where it is cheaper to match the parts than to try to get each cylinder and each piston exactly the same.

Parts which are not made to specification can frequently be used in selective assemblies so long as they are within salvage limits, but in such cases one of the parts must be within specifications to maintain interchangeability. Certainly two wrongs never make a right, especially when replacement parts are to be of later service.

## PRECISION WORK

Time and again, the quality of the work has been mentioned as a limiting factor in the use of line production. Fundamentally, the quality of a product has very little to do with the arrangement of equipment and work areas, and only indirectly does it limit the possibilities of line production.

**Precision Fabrication.**—On fabricating lines, precision is largely a matter of tooling. It is not even necessary that skilled hands operate the machines if enough money can be spent on the equipment. It is a common occurrence to see unskilled workers at modern production machinery making a quality product obtained on job-shop equipment only with expert operators. For example, a machine can be designed so that an unskilled worker inserts a piece to be machined between guides; he turns the switch or presses a pedal, and the machine goes through its cycle automatically, returns to the ready position, and stops. This principle of automatic performance of jobs that formerly required great skill is one of the primary features underlying mass production and is often applied in production lines. If the quantity of production on any line is sufficient to keep the machinery busy and pay for the equipment and tooling, line fabrication can be employed regardless of the quality of the product. Thus, since more exacting quality justifies specialized equipment, and since this equipment is peculiarly adapted to production lines, it frequently follows that the more precise the quality demanded the greater the possibility of line production.

Where quality demands lengthening of operating time and requires too many machines for line production, it is generally found practical to use a high-speed, special machine which will handle the complete operation. In other cases, the accuracy required in the setting up of equipment means that line production may be demanded. One company attempted the manufacture of certain aircraft wing frames, trusses, and hinges in a functional layout but soon changed to a progressive line. The time required to set up the tools and to get each new operation running accurately was so long that frequent machine changeovers actually required a greater number of machines. Moreover, so much work was spoiled in adjusting each new setup that the cost of changeover was prohibitive. Production lines were therefore established for the work, and machines remained idle when not needed. In this case, high quality literally demanded the use of line production.

Certain limitations surrounding line production are emphasized when quality and precision work are especially sought. Line-production jobs seldom make use of highly skilled workers. The less skilled the employee, the less his operation can be relied upon, and the more important do inspection checks become. Then, too, setup men or job-setters must be depended upon to a much greater extent to make a precision line function properly. With loose setups of equipment it is impossible to hold the proper quality unless operators are themselves skilled.

Where a concern already has skilled help and is equipped with general-purpose machinery, a change to line production will give little advantage as far as workmanship is concerned. The responsibility for quality still rests upon the operator rather than upon the machine. Frequently, also, it is cheaper to train skilled workers than to buy specialized equipment and to employ semiskilled help. However, as soon as the volume becomes sufficient to keep a machine busy full time, it will be economical to begin fitting the machine with special tooling.

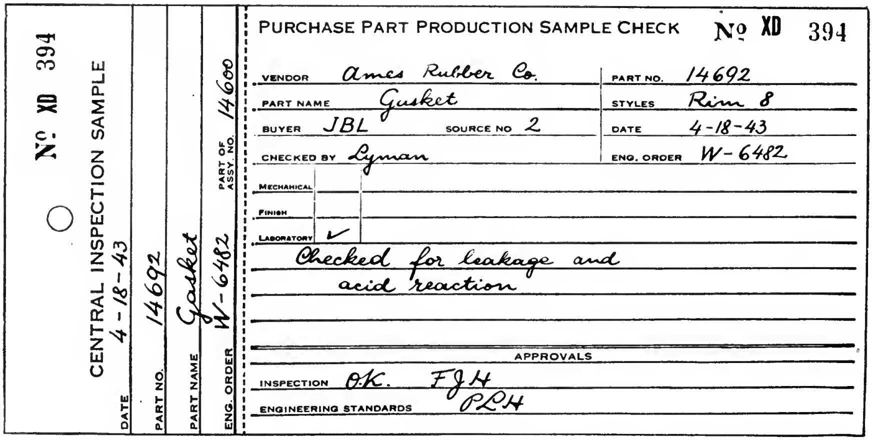
**Precision Assembly.**—In precision-assembly work, there are also conditions under which line production is less advantageous. Where operations cannot be standardized, the assembly line will have to be very flexible for balance. Again, where assembled parts are not interchangeable but have to be fitted and adjusted to limits of precision which are beyond the range of the fabricating equipment, it may be desirable to have one operator make the complete assembly, for he now can keep in mind the peculiarities of each assembly on which he works, making allowances for these variations as he proceeds. When the unit fails to pass inspection, it will be returned to the same assembler, for he can recall the special difficulties encountered.

The very placing of responsibility upon one person for a complete assembly may give a better quality, particularly where it is impossible to measure the workmanship between the various operations or where the worker causing the faulty work cannot be identified. Many companies limit their use of line production in order that they may assign definite responsibility to each workman for a complete assembled unit.

Line production in assembly is restricted by the ability of parts to be interchanged and is limited by the cost of obtaining that interchangeability. Usually, a comparison of the costs of obtaining accurate work in the fabricating operations with the cost of performing the extra fitting operations in assembly determines whether parts shall be made interchangeable. This does not necessarily involve the question of line production at all. It is far better to make an over-all comparison of assembly by line production versus job-lot production. All the intangible savings as well as the demand for interchangeability should be considered before a final decision is made as to whether a line should or should not be used.

## INSPECTION

The biggest problems in line production come with the changeover or setting up of any new production line. Getting



No XD 394
CENTRAL INSPECTION SAMPLE
DATE 4-18-43
PART NO. 14692
PART NAME Gasket
ENG. ORDER W-6482
PART OF ASSY. NO. 14600

PURCHASE PART PRODUCTION SAMPLE CHECK No XD 394

VENDOR Ames Rubber Co. PART NO. 14692
PART NAME Gasket STYLES Rim 8
BUYER JBL SOURCE NO 2 DATE 4-18-43
CHECKED BY Lyman ENG. ORDER W-6482
MECHANICAL
FINISH
LABORATORY ✓
Checked for leakage and acid reaction
APPROVALS
INSPECTION OK. FJH
ENGINEERING STANDARDS PLH

FIG. 88.—Check tag to indicate approval of parts purchased from sources outside the plant. Samples of purchased parts should meet inspection approval before the parts are delivered in quantity to the production lines.

the line installed to produce parts of the proper quality is a primary objective of the production engineer. Long before production gets under way, samples of material and purchased parts must be submitted by each vendor, checked by engineers, tested by the laboratory, and approved by inspection. Figure 88 shows a tag for checking sample purchased parts. Should the samples prove unsatisfactory, outside, or field, inspectors are sometimes sent to vendors' plants to educate them as to quality requirements. Once the purchasing department has been notified that the parts are adequate, it can proceed to purchase the parts by the samples submitted. This same procedure generally applies for any changes made in purchased parts or material after the line is operating. A similar routine is followed for initial parts made within the

To: F. Dean From: Inspection Date: Jan.28,1942

TAIL GATE PANEL - Part #844654 - Rev. "C"

One sample submitted by Plant 3. Die tryout was checked as follows:

1. The 2-5/16" dimension locating the two groups of three holes checks 1/64" minus on one side and 3/64" minus on the other.

2. The 1-3/4" dimension locating the two groups of two holes in side flanges checks 1/64" minus.

3. The 15-5/8" width checks 1/32" minus to 1/64" plus.

Rejected - The 2-5/16" dimension locating the three holes as noted in item No. 1 should be corrected. This was previously reported on January 13, 1942.

H. Amory

CC - Messrs. E.L.Merrill
M.C.Richardson

Fig. 89.—Typical inspection report on tryout of tools.

plant, for they must also be checked to make sure they will be satisfactory in the final product.

All equipment used in a new line-up should be thoroughly checked. Where dies, for example, are made by outside vendors, first, the samples run by the diemaker from these dies are submitted for approval. When the die itself is received, it is checked at the plant, and samples are run off for die approval. Figure 89 shows a disapproval notice concerning a stamping sample. When passed by the parties interested, the sample parts are sent on through the fabricating operations and checked by assembly inspection for functioning, finish, strength, and the like.

Gauges are generally selected by the inspection department. Where new gauges must be designed, assistance of the tool designer may be needed, and his samples may be submitted to the inspection department for approval. All incoming gauges should be thoroughly checked by the inspection department.

While this early work is directed toward ensuring a satisfactory final product, equally important is the avoidance of interruptions in production. Thorough inspection of equipment and material samples must be made if the line is later to run without delays due to rejections. Therefore, the inspection group is especially busy during the pilot lot or trial run. Once the job is properly under way, it generally proceeds with little change, and the problem of obtaining quality becomes one of minor adjustments, tool change, and wear and tear.

**Receiving Inspection.**—There are some who believe that thorough raw-material inspection is generally less important in line production than in job-lot manufacture. They feel that under the job-lot system, if the raw stock is below specification and the first process inspection does not take place until after several operations, the whole batch will go through these operations before the defect is noted. A great deal of time, labor, and material will have been needlessly expended. On a production line manufacturing the same part, only a few pieces will have progressed through the several operations before the inspector discovers the defects.

This reasoning holds true, but one important fact is overlooked. When the defect is discovered on the progressive line, the entire line may have to be shut down until the error is corrected or more material is obtained. If the incoming pieces reach the line without being checked and are rejected at that point, then the line cannot operate, workmen will be idle, and subsequent departments or shipments may be delayed. The line-production shop, therefore, cannot wait to find defective stock at the point of usage. Moreover, inspection of incoming material is of greater significance in line production because line operators are not as skilled or responsible as job-lot workers and seldom have as intelligent supervision. The operator who is only production-minded cannot be relied upon to check the material; he will always use the stock if he possibly can.

The methods of inspecting incoming material do not differ significantly in line production from batch-lot manufacture, except that there are usually larger quantities of fewer items and deliveries are more uniform.

INSPECTOR'S NAME J. Byrne SCHEDULE NO. OF THIS UNIT 51

BADGE NO 17-68 DATE 11/19/43 SHEET NO 1 OF

| DEFECT NO. | NATURE OF DEFECT | REPAIR BY NO | INSPECTOR'S O.K. |
|---|---|---|---|
| 1 | Grind front support part flush | 8-103 | J.B. |
| 2 | Grind 63" dimension to size. | 8-47 | |
| 3 | Clean slag off welds | 8-103 | |
| 4 | Gas line bracket in motor compartment shy | 8-63 | J.B. |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

Fig. 90.—Inspection log sheet traveling with each assembly unit on the line. The inspector in each station marks down the defect. When the correction has been made the repair operator writes in his badge number. If the repair is satisfactory the inspector o.k.'s the work by initialing the last column. Obviously this type of inspection log can be used on slow-moving lines only.

**Inspection on the Line.**—Some plants perform all inspection operations in a central inspection area after every operation. If this were a necessity, there would be little value in setting up a progressive line. In line production, *centralized inspection does not exist* except in the initial or final inspection or between lines, and even here it is seldom completely centralized. Rather, each inspector must be placed in the line at a critical point and must be able to keep up with the flow of production. For this reason the inspection report may travel with the work through the entire line. Figure 90 shows such an inspection log.

When an inspector shuts down a machine in job-lot production, he is delaying only one operation. In line production, if one machine is not producing satisfactorily, to shut it down may affect the whole line. This, together with the less skilled operators, tends to put *greater responsibility on the inspector.*

When the plant is laid out for job-lot manufacture, each department is responsible for the quality of the work done within its stated area of jurisdiction. An attempt is made to fix the blame for faulty workmanship upon the proper department. In order to accomplish this, there is an inspection wherever there is a transfer of responsibility. Frequently, this inspection occurs only to assure foremen that they are receiving no defective work for which they may later be charged. Sometimes, as parts leave the releasing department, an inspection takes place which will be a clear duplication of the inspection by the department receiving the material. When parts move along a production line, *interdepartment inspection is eliminated;* for here all operations on the line are under the same supervision. In the same way, inspection of material coming from temporary storage is eliminated, for material which must be stored between operations is kept in the line if possible and is certainly not moved out of the department. This reduces not only the amount of inspection but a great deal of potential friction between department heads.

In order that they may not hold up production, *inspectors also must be balanced into the line.* Although they are rarely overloaded, they may benefit considerably when their time is more evenly divided in terms of the work to be done. Where proper balance of inspectors is desired, time studies will frequently be called for. These figures can be used to help the chief inspector make an intelligent assignment of his inspectors to the line. These studies may also be used as a basis for determining the number of inspectors allotted to the inspection department. In the balancing of inspectors along the line, it is frequently possible to combine production or other nonproductive work with inspection operations, though the dual responsibility of the inspector may not be satisfactory if quality is especially important. In a new line, it is customary to establish extra inspection stations which may later be eliminated. This does not necessarily mean that there will be more inspectors, for when production starts, it will probably be at a reduced pace.

Inspectors are generally assigned to certain lines and do not move to other areas. There may even be several different types of inspectors covering the same stations. On final-line inspection for aircraft, for example, there may be inspectors of tubing, wiring, hydraulics, and mechanical installations. The responsibility of inspectors must be so drawn as to prevent overlaps or gaps in the points to be inspected. In cases of lengthy lines where the production organization is divided, it is generally desirable to have the inspectors cover the operations within the same limits as production supervision, although they may have to move down into the next supervisor's section in order to have time to inspect the work adequately. In this way, *the spread of inspectors along the line conforms to the arrangement of production supervision* so that the inspector is always working with the same foreman or group leader. Where there are two or more lines parallel to each other, inspectors may cover the same number of stations on each of these lines. In this way, the skill and training required for each inspector is less, since he needs to know only the operation done at two or three stations.

**Repair Problems.**—The handling of repair operations and defective work is much harder on a line than in job-lot production. If this work has to be conducted off the line, it may mean moving the parts out to another area and later returning them. Usually, such interruptions cannot be allowed, and the repair must be handled in some other way.

It is seldom possible for the operator to make his own repairs, since generally the work has moved down the line beyond him before the need for correction is realized. However, regular repair operators who know all the jobs are frequently maintained to "pick up" the imperfect work. These men may be assigned to specific repair stations in the line. They may move along the line as utility operators depending on the frequency of errors. In fact, group leaders or utility men often perform the repairs that can be quickly made. If subsequent operations are dependent on the correct work, the piece will have to be repaired at the point of the error. This work can be done beside the line, the piece being moved aside

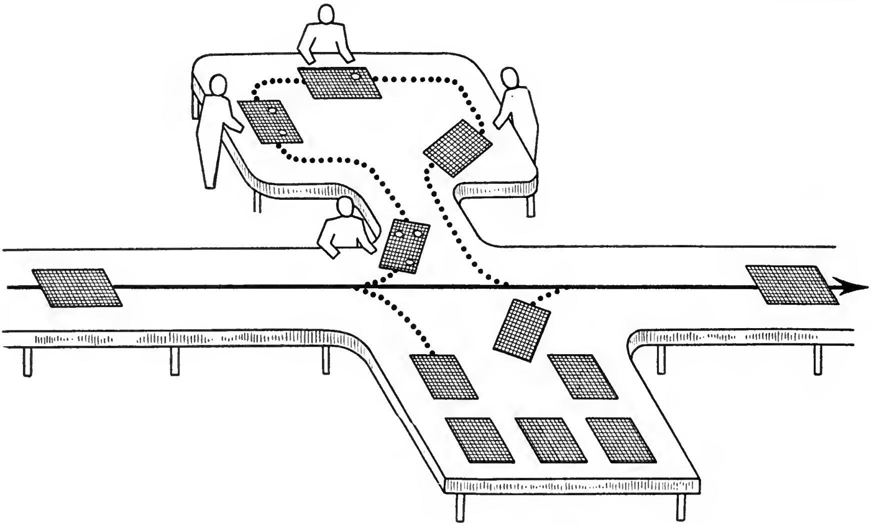


FIG. 91.—Correction station in the line. Faulty parts are sidetracked and good parts substituted from reserve bank. White spots represent parts to be corrected. *(From Gesellschafts und Wirtschaftsmuseum and the International Management Institute.)*

to await the repair man. Sometimes a shunt repair line is employed adjacent to the line, as shown in Fig. 91.

Frequently, it is easiest to let the defective work pass along and be corrected at the end of the line. Where this is commonplace, as with paint scratches or minor adjustments, regular make-up stations are installed, though the repair area can seldom be so well planned. Where there is an epidemic of minor repairs that do not require technical or all-round skill, production workers may be held overtime and moved down into the repair area to make the corrections. Sometimes it is in this way possible to take advantage of the psychological value of having each operator responsible for his own repair work, an advantage which may be lost if others make the

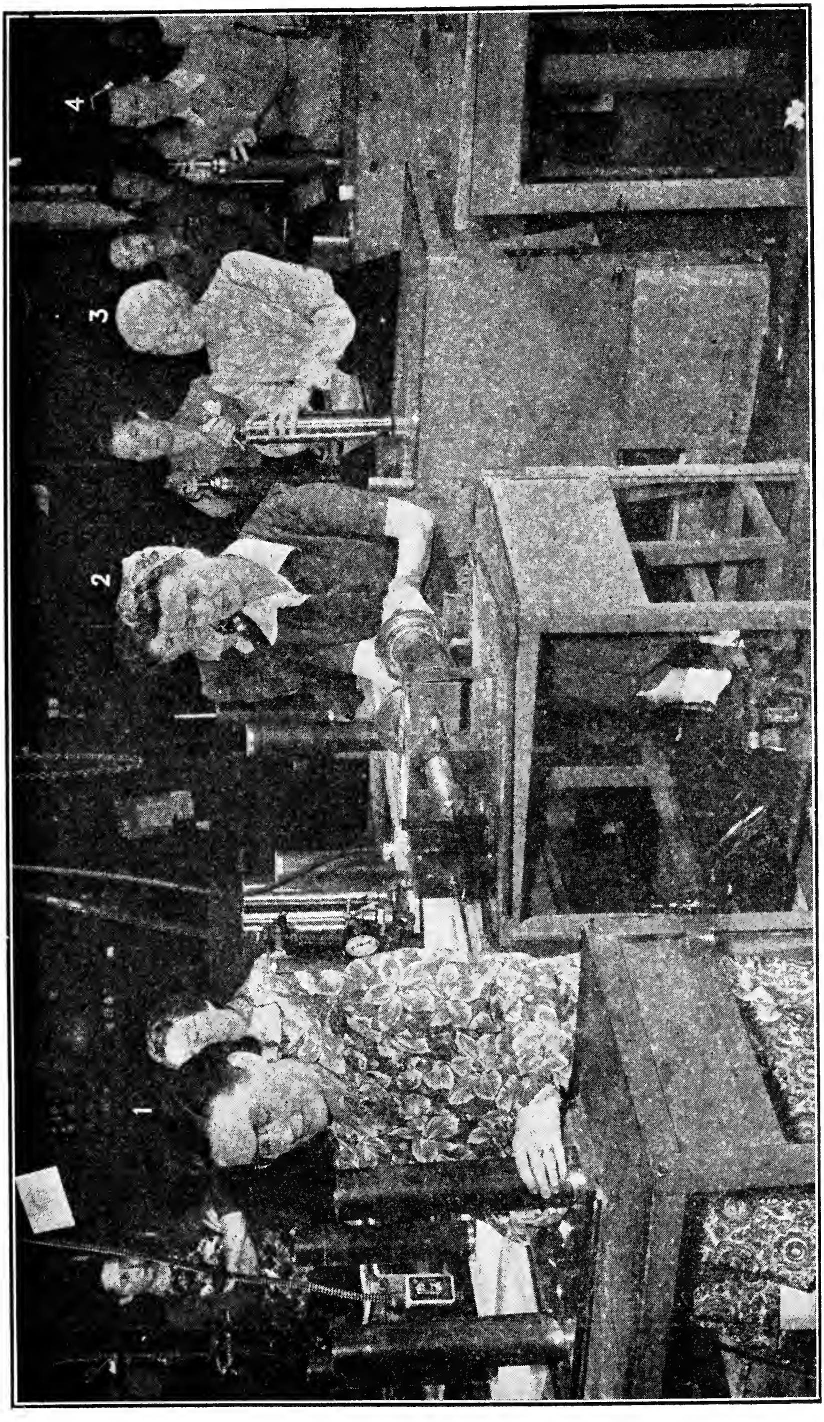



FIG. 92.—Inspection line for shell casings. The work moves along a belt conveyor and each operator inspects one particular dimension as follows: 1, Shoulder flange; 2, body diameter; 3, primer hole; 4, head thickness.

repairs. The difficulty of shifting operations and unbalancing the line is so great that, except where defective parts can be banked up, it is more practical to have repair men.

When work has been pushed down from the production department into the repair or make-up department, some attempt is made to hold production responsible for all incomplete or faulty work. If production can be charged for these

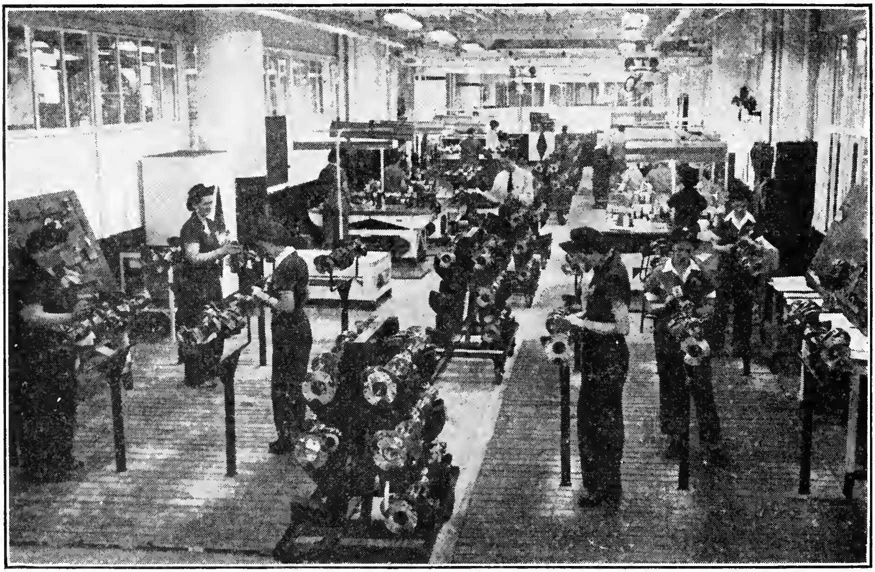


FIG. 93.—Inspection line for crankshafts. Note the float on racks between work areas. Racks travel on wheels guided by one U-channel. (*Courtesy of Society of Automotive Engineers.*)

incomplete jobs, the cost and number of corrections will be lessened; such work is generally much more expensive than the same operation on the line. This may have a beneficial effect upon factory overhead. The shop executive is generally more anxious to get out his day's production than to concern himself about small increases in cost. However, when his performance rating or the pay of his men is based on the number of units accepted, or incorporates the hours of repair time, an incentive to reduce faulty work is provided.

**Other Inspection Problems.**—The use of an inspection line can in itself effect great savings in inspection cost. All the advantages of line production are possible in inspection by applying the same principles. Here, too, the operations can be analyzed, and each man needs to know only how to inspect one dimension or how to use one gauge. Figures 92 and 93 show examples of two inspection lines. A midwestern plant set up a final inspection department by arranging the inspec-

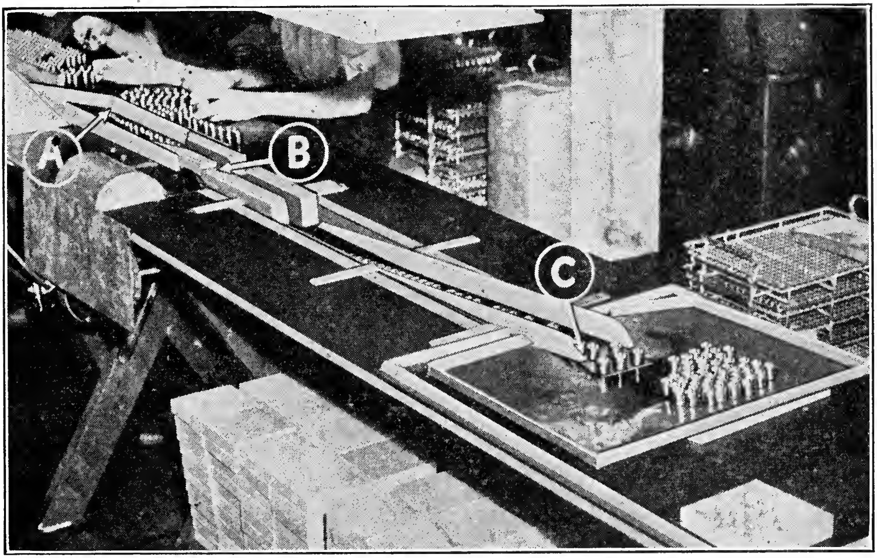



Fig. 94.—This is the end of a line where parts are packed for shipping. Inspection is completed at point *A*. At point *B*, the parts are released to a second conveyor which runs through a container of rust-proof oil. The parts pass through the oil and up to point *C*, where they wait on the table for packing. Excess oil drains from the parts while they are moving up the incline. (*From The Iron Age.*)

tors at stations along the ends of each production line instead of grouping them in one department. This plan eliminated 250 ft. of trucking and did away with the entire final inspection area.[1] A similar but different situation is seen in Fig. 94, which shows a processing station built into the end of an inspection line.

In some cases of line production, it is difficult to trace responsibility for defects to an individual machine operator. Conversely, the idiosyncrasies in the work of operators can be readily identified by the inspector, although to the layman the

[1] "Report to Industry," *Mill and Factory*, June, 1943.

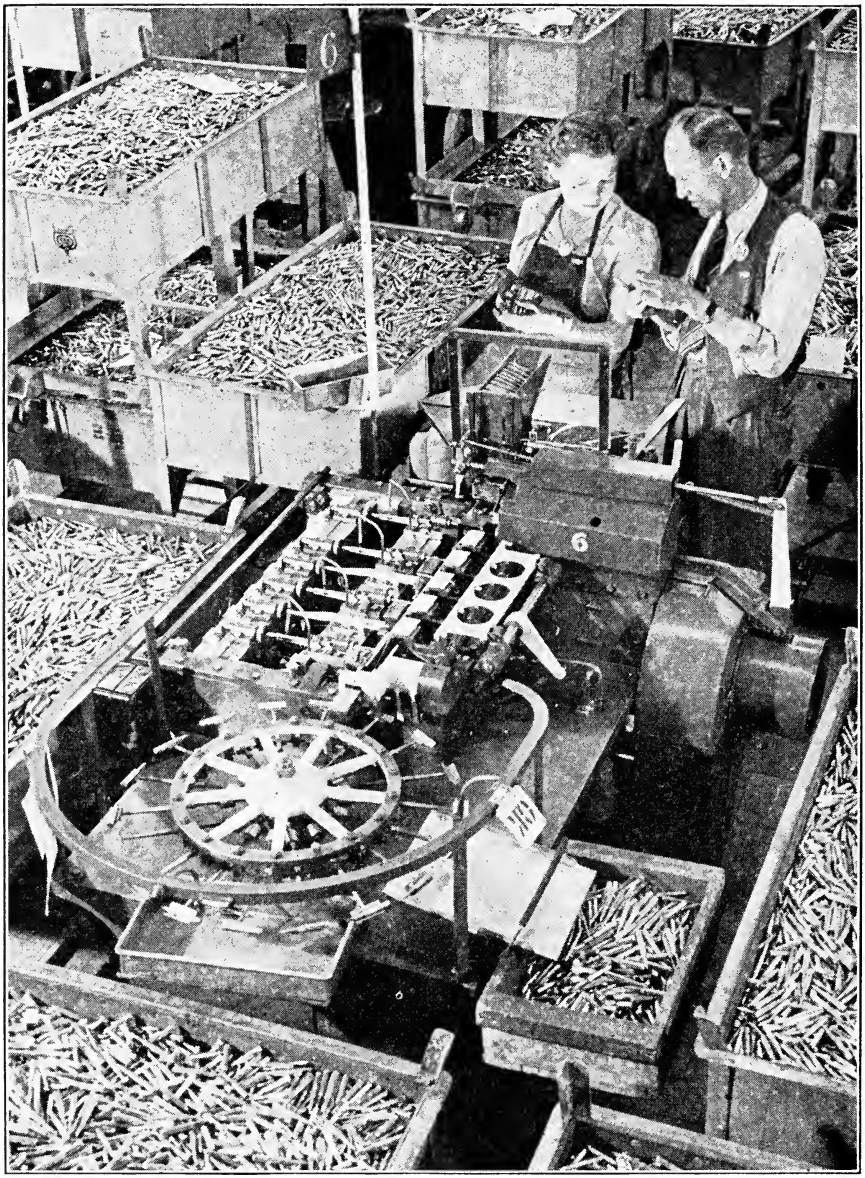


FIG. 95.—Automatic inspection machine. The cartridge is placed in the hopper by hand. It goes into the turret (marked 6) where its dimensions are checked by the first gauge. As it goes through the next five stations other dimensions are checked, the cartridge being ejected if any dimension is wrong. It then goes to the saddle extension of the wheel. If too heavy or too light, it is knocked off into the pan. If correct, it cuts no obstruction and is dropped off in the O.K. box. (*From Fortune, photographed by Pat Coffey.*)

piece may look the same as any other; for when the same operators work on the same operation and the same item day in and day out, the inspector learns to recognize the work of each operator. Where there are many operators in the line, each may have to identify the pieces on which he works by

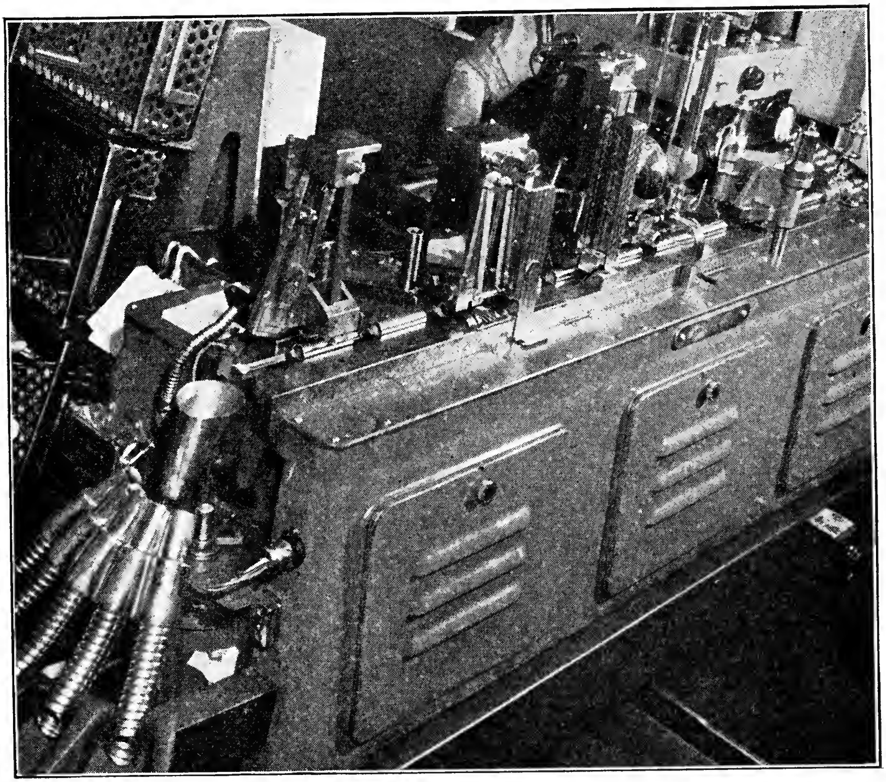


FIG. 96.—This piston pin gauging machine automatically checks six measurements and sorts the pins into sizes varying only 1/10,000th of an inch, discarding any that are over or under tolerance. The pins are fed into the machine at the right, travel through the gauging mechanisms, and drop into the sorting tubes at the left. (*Courtesy of Ford Motor Company.*)

some means similar to those explained in Chapter V. Perhaps the easiest way to deal with this problem is to avoid placing the blame and to hold the group responsible by paying for only the good units produced. This does not mean that an analysis of the causes of rejection can be eliminated; a study of such figures will usually point to significant improvements that can be made. Indeed, such data must be available to the chief inspector if he is to determine an economical placing of his inspectors on the line.

Automatic gauging may be used in any form of mass production, whether on production lines or in job-lot manufacture. Many kinds of automatic inspecting devices are on the market, and the number is increasing. The advent of fully automatic inspection may in the near future revolutionize the quality problem on many production lines. Many of these gauges measure several dimensions simultaneously. In other cases, the specifications are checked as the work passes through a series of stages, the inspecting unit being not unlike a serialized inspection line built into one machine. Figure 95 shows such a device in use for checking ammunition, and Fig. 96, a similar inspection of a machined part. Naturally, the high price of these gauges and the high maintenance costs do not warrant their use except in high-volume installations.

## SALVAGE

Salvage operations are similar in line production and in job-lot manufacturing except where the amount of material handled may introduce differences. With many parts being produced and with little direct cost on each, it is often cheaper to scrap spoiled work than to repair it. As far as fabricating lines are concerned, it is difficult to generalize whether the amount of material to be salvaged or scrapped will be larger by one method of manufacture than by the other. Errors can usually be found and corrected more quickly on line production, so that spoiled material does not pile up in large amounts. On the other hand, if the error slips by the inspector, a great many defective pieces can be made before they are detected.

On an assembly line, careless use of material is more likely. Since there are a large number of seemingly inexpensive parts on the line and many open storage bins, much waste and disregard of stock occur, resulting in many pieces being scrapped unnecessarily. On certain assembly lines, salvage men spend full time sorting out parts dropped by production workers and returning them to their proper bins.

The control of scrap cost is generally easier under line-production methods. In functional layout of equipment, information must be obtained from each individual department to determine the percentage of spoiled work on any one part. This involves a check on the total production before

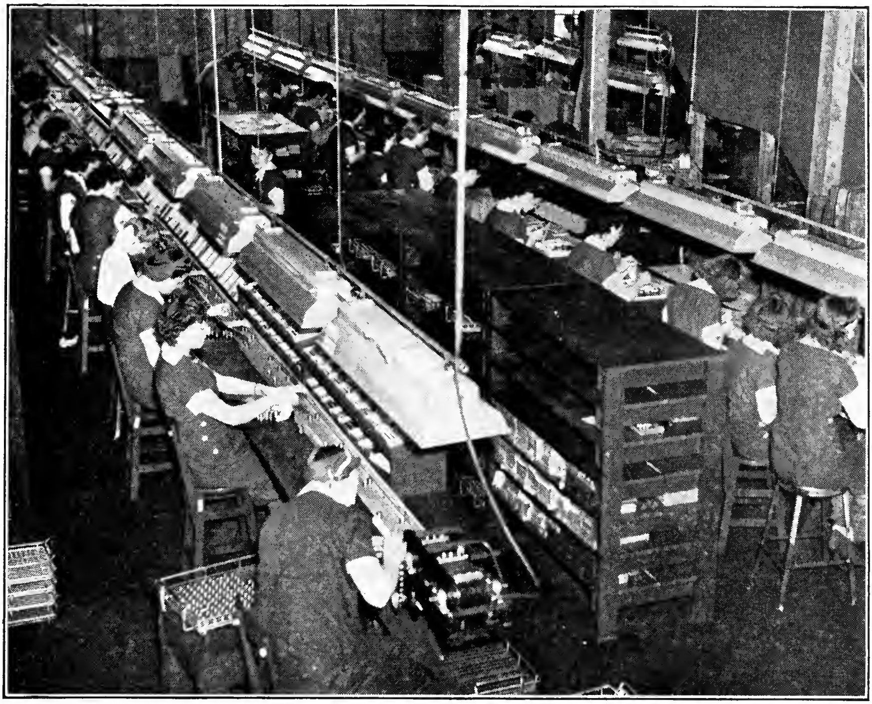


FIG. 97.—Two progressive inspection lines. O.K. parts are removed at the far end and packed for shipping. The rejections which occur at each station are placed in the individual boxes which appear in an inclined position across the belt from the operators. Faulty parts are thus accumulated according to kind of error. This simplifies classification, repair, and salvage. (*From The Iron Age.*)

and after the waste occurs. Frequently, it necessitates extra counting and inspection with obvious duplication of effort. On a production line, figures on scrap losses for each product can be obtained by an initial and final inspection in but one department. On the other hand, it will be more difficult to get waste figures on any one process or operation throughout the plant if such figures are desired. Where parts are inspected on an inspection line, the defects caused at a certain fabricating operation are always found by the same inspector, as Fig. 97 illustrates.

The predicting of shrinkage, or scrap loss, is also easier on line production. Where the work is repetitive, these data can easily be translated into statistical terms. In fact, the actual number of rejects often shows but slight fluctuation from a mathematical average. This allows much greater accuracy in materials and production control. Knowing the number of rejects and spoiled pieces to be expected, the schedule clerk can easily determine how many pieces (gross) should be introduced at the beginning of the line.

### EXECUTIVE READING

"Production Pace Set by Quality Control," *Automotive Industries*, Vol. 83, No. 7, p. 284. Joseph Geschelin discusses quality control in the automotive industry.

"Inspection Time Reduced on Aircraft Parts," *The Iron Age*, Vol. 152, No. 12, p. 67. V. E. Childers maintains that the use of master tools assures interchangeability.

"A Sampling Inspection Plan for Continuous Production," *Annals of Mathematical Statistics*, Vol. 14, No. 3, p. 264. H. F. Dodge gives the procedure and theory of a sampling plan for inspection in continuous manufacture.

"The Importance of the Statistical Viewpoint in High Production Manufacturing," *Journal* of the American Statistical Association, Vol. 36, No. 213, p. 50. P. L. Alger states briefly the value of statistics in quantity production.

# CHAPTER XIII

## MAINTENANCE

Certain aspects of maintenance are especially significant in line production. To set up equipment in a progressive sequence is courting trouble; if any one of the machines within the line breaks down, the flow is interrupted and all subsequent operations must stop. Also, parts coming down the line quickly create congestion before the disabled machine. If the line conveyor itself gives way, work will be held up in every station. For these reasons, an unforeseen delay that cannot be immediately remedied is particularly serious.

Whenever a line is shut down, the company loses money. There is the loss occasioned by paying for idle labor in the event that workers cannot be readily transferred. Also lost is the income on the number of finished units which the company could have produced. Interruption in production schedules may have harmful effects on other lines and on worker morale. It is essential, therefore, that the line flow be maintained at all cost. So important is this continuity that in one plant the maintenance chief stated, "When the final line goes down for three minutes, you have lost three units, but when it is down for ten minutes, you have lost your job." In fact, as a protection against any charge that his department has held up shipping schedules, one maintenance supervisor uses a time-recording device which registers whenever the final line stops and indicates exactly how long it is disabled.

This problem is naturally more important where machinery is involved. If the work is performed by hand with small tools, a broken or misplaced tool is less likely to be serious for it can be easily replaced. It is on the powered-conveyor line that the problem becomes most critical, for on such "tight" lines there is very little float between operations.

## JOB-LOT AND LINE MAINTENANCE

A comparison of the maintenance work in job-lot manufacture and flow production shows several differences. In line production, aside from the likelihood of a greater variety of machinery in total as well as much specialized equipment, there are different machines and tools in each department. With departments arranged by product rather than by process, maintenance work becomes functionalized to a greater degree. Maintenance men are no longer assigned to certain types of machines, for now this equipment is scattered throughout the plant. Instead, they are stationed in specific departments. However, to get the same service as in functional layout they are likely to specialize on a certain type of work, particularly where there is a variety of complicated machines. For example, there may be electricians, hydraulic men, and mechanics maintaining the same line. Each will have a specific job to perform either periodically, irregularly, or in case of emergency. Because of the complicated relay system on one specialized machine, an electrical attendant was kept on hand full time to repair it. However, this functional skill facilitates the transfer of maintenance help from one line to another.

To establish control over maintenance, there should be a maintenance headquarters in either type of layout, located as centrally as possible. As for service on the floor, there is a tendency toward greater decentralization in line production, largely because of the need for faster repair in the event of breakdown. Decentralized maintenance cribs provide better protection for production, since they are closer to the lines they serve. This arrangement, of course, complicates supervision, for it is hard to keep men on the job or on call when they are scattered about the plant. Moreover, there is likely to be a greater duplicaton of repair tools and supplies, in view of the mixed machinery and different maintenance specialists required on each line.

**The Greater Cost of Line Maintenance.**—Maintenance expenditures in line production may run higher than those in the job-lot plant because of the greater difficulty in maintaining machines of one type when these are spread about the shop. Because of the many different machines and their specialized nature, maintenance in line-production plants calls for greater versatility. Machines placed at odd angles to facilitate handling are often quite inaccessible to the maintenance men and more difficult to move or to repair. Furthermore, production-line workers, as a whole, take less interest in, or lack training for, the keeping of their equipment in good operating condition.

A further source of increased maintenance cost in line production is the demand for quick repair in order to avoid stopping the entire line. Repair men are often kept ready and available even if idle a large part of the time for lack of other work.

More money must also be spent for preventive maintenance, as the prevention of machine and conveyor "down-time" is really the primary aim of the maintenance group. As insurance against breakdown, an intensive program of preventive maintenance is standard practice in line-production plants. Such prevention may be cheaper in the long run to the company as a whole, although it may raise the current operating expense of the maintenance department. Incidentally, one method of measuring the effectiveness of the maintenance work is to compare the record of down-time of conveyors and machines with maintenance expenditures.

## SERVICING THE LINE

While it is true that the maintenance department must be in the nature of a fire department, it must also be a fire-prevention department through the application of anticipatory maintenance techniques. Most line-production manufacturers are firmly convinced that preventive maintenance is the least expensive and most satisfactory insurance for meeting their required production schedules. Experience has shown that maintenance becomes expensive whenever it becomes solely curative.

**Preventive Methods.**—In order to implement preventive maintenance, it is advisable to have inspection crews. One automotive company, for example, has an inspection crew which checks all critical conveyors every day. Another crew is constantly at work checking and inspecting motor-generator sets, transformers, dust on insulators, and the like. A meter man is continually in the shop taking load readings on motors to check overloading. Then there are groups of oilers, greasers, and carpenters for floor work, the roof gang, and many others to look after the drains, manholes, and air and water lines. Ordinarily, it has proved advantageous to set up an inspection schedule for these men. It is sometimes found more desirable to have an inspection schedule of the equipment. Compressed-air tools, electric screw drivers, soldering irons, and numerous other small tools need not necessarily be inspected out on the line, but some system should be inaugurated to check them periodically, if not on the line, then in the central maintenance crib. To ensure continuity of service, one company requires that once every 2 weeks, every portable electric tool in the plant be picked up and brought to the maintenance shop for inspection. As a result, there is practically no trouble with these tools along the line. In some shops, this job is left to a specific tool-trouble group whose responsibility it is to see that tools on the production lines are in proper working condition at all times.

The rebuilding of equipment may be the function of the machine-repair or mechanical-repair department and is not always within the bailiwick of the maintenance department. The latter group will have men on the floor to repair machines at the line or to arrange for their removal. Machine repair is an important aspect of any fabricating line, and the men who do this work should be members of the machine-repair or maintenance departments, not merely tool-trouble or machine-service men. As a general rule, therefore, operators, and sometimes even the job setters and supervisors, are not allowed to repair machinery. It has become necessary in some cases to lock the electrical panel; for when an overloaded relay kicks out, the operator is apt to plug it in again himself, holding it with a match. This can be a dangerous procedure, for it is likely that the hard stock or the dull tool which originally caused the kick-out will result in a dangerous overloading of the equipment.

To repair a piece of equipment in the line, it is necessary to build up a bank ahead or to interrupt production. Work of this nature which affects the continuity of the line can often be done on week ends or at night. This applies also to cleaning out paint booths or other equipment which is likely to be in use full time.

Another important consideration in preventive maintenance is a system of electrical wiring which will not only permit flexibility of equipment but will protect the line against closing down for lack of power. Spare banks of transformers and intricate electrical cross-switching can be installed so that power to any part of the plant can be cut in through another lead.

Preventive maintenance is essential on conveyors. Breakdown here is as troublesome to the line shop as a broken pipe is to a chemical plant, or a breakdown in elevators is to a multistory job-lot plant. Particularly is this important where the conveyor is scheduled to meet another line. All powered-conveyor lines will be equipped with start-and-stop switches, and on long lines it is common to have several such switches. When congestion occurs on the line, any one of a number of supervisors can press the button to stop the line. A call will be put in to the maintenance crib, or trouble lights will flash, automatically indicating the point of shutdown.

A variety of protective devices has been developed to aid maintenance, including such items as shear pins on conveyors to permit rapid repair at one specific point; electric eyes or limit switches to protect certain parts from going beyond a desired station; automatic overloading switches; fuses; and other electrical controls. Telltale pilot lights are frequently installed on electric circuits as a protective measure.

Still another way of preventing machine down-time is the development of operator interest. One New England manufacturer recently changed over his fabricating operations to a progressive line. After the line was in production, the eight or ten operators were put on gang piece rate, and the machine breakdowns decreased noticeably. This apparently resulted from the realization on the part of operators that their equipment must be kept in working order, since it meant money in their pockets. Similar interest can be developed by having setup men or machine adjustors included in the pay group with the productive workers, so that they also become interested in seeing the machines dependably maintained.

## CARING FOR BREAKDOWNS

Since the complete prevention of breakdown is impossible, and since it is important not to interrupt production, it is obvious that emergency servicing must be preplanned. The maintenance workers must be trained in the exact procedure to follow in various kinds of emergencies. The most highly organized maintenance crew is usually on the final assembly line. It is like a lifesaving station or minute-man group. When the line stops, the maintenance men run to their stations and carry out their specific assignments. Some plants even go to the extent of having "fire drills" for their maintenance crews. Figure 98 illustrates the speed which is often called for.

**Protection Against Shutdowns.**—Every effort should be made to prevent a breakdown from occurring. But should it occur, there are several ways to prevent its becoming a serious problem:

*Large Floats.*—In order to take care of emergencies or trouble in the line, many plants carry a large float throughout the factory with material in different stages of completion. Protection of this kind against particularly temperamental machines or the breakdown of delivery conveyors is clearly wise. This is an easy solution, although it sacrifices much of the benefit of line production; for if material is held in large floats and safety banks, the gains resulting from reduced goods in process and more rapid turnover are lost.

*Stand-by Equipment.*—Some companies, especially those with critical operations which must be performed on very delicate machinery, carry excess machinery in readiness for immediate substitution in case the regular machine fails. This is an expensive practice and seldom gives complete protection. It is well-nigh impossible to have stand-by equipment for all machines, and frequently it will be the unprotected

FIG. 98.—Rapid notification of breakdowns and speed in making necessary repairs are particularly important in line production. (*From Factory Management and Maintenance.*)

machine which fails. Stand-by equipment for critical machinery may often be retained as protection for several lines. One company uses a method of rotating forging and stamping presses. Some of these machines are always out of the lines being overhauled and repaired. These constitute the stand-by equipment and can be swung quickly into the line with overhead cranes in the event of breakdown. A less expensive plan is to keep on hand spare parts so that repairs can be made quickly. It is not expensive to carry spare jigs, fixtures, and adaptations and is common practice to carry extra tools of all kinds.

*Postponed Operations and Make-up off the Line.*—Another method but a less feasible one in manufacturing operations is to by-pass the equipment that is down and to perform its operation later in the repair department or tool room or after shift change.

In some cases when a machine fails, it is still possible to perform the same operation on some other equipment or in another department. This is usually difficult and means crowding other work or introducing overtime. Or, in cases of extremely slow production, where a serious breakdown may last for several days, the work may even be sent outside the plant.

*Rapid Notification System.*—A further method of avoiding a long shutdown is to have a maintenance department trained to work with a rapid system of notification. This may be in the form of horns, call lights, or a loud-speaker system. Colored lights can be used to indicate the nature of the trouble or its location on the line. Other forms of rapid intraplant communication can be employed to notify the central maintenance office or department cribs, so that the repair crews can get to the point of trouble quickly. It goes without saying that the repair crews must be readily available.

*Duplicate Lines.*—Where there are two or more similar lines performing the same work, a breakdown is less serious, for there is still one line which can protect succeeding lines to some degree. At least, it is possible to get out a goodly proportion of the scheduled production even if necessary to operate one line overtime.

**Conveyor Breakdown.**—When conveyors fail, they may cause not only a shutdown of several lines but also a confusion in the scheduled sequence of parts. If the conveyor is merely used for delivery, parts can be taken from a bank beside the line. If the parts are not too heavy, the men can work back along the stopped conveyor and carry the parts to the proper working point. If the delivery conveyor is scheduled, workers may use both these methods in order to keep the proper sequence. Otherwise, when the conveyor again moves, scheduled parts will not meet the correct assembly.

If a delivery conveyor fails but the line being fed does not stop, the repaired conveyor must be sped up until it is again in step with the assembly line. Where equipped with a drive which allows it normally to run faster than the line, the feeding conveyor will catch up by itself until it is again being indexed by its control mechanism.

Guards should, of course, be put on conveyors, not only for safety purposes but for the purpose of keeping parts and tools from jamming in the machine or conveyor. In most instances, breakdowns are caused by carelessness. At other times, there may be actual sabotage instituted, perhaps by a workman to gain a rest or to discredit the foreman or another operator. In order to emphasize the importance of the down-time of conveyors, one maintenance supervisor kept mounted on a board in his office an exhibit of specimens that had caused line breakdowns.

When a machine fails, there is always the problem of the idle operator. Here solutions depend upon particular circumstances. Usually, he helps to repair the machine, works elsewhere in the line, or is moved to another job. In plants using group-incentive plans, the operator assists other workers in his group.

# CHAPTER XIV

## PERSONNEL

A characteristic of line production is the extensive division of labor. Line production provides a means whereby unskilled workers can produce parts and assemblies which otherwise would require an all-round skilled operator.[1] The shoemaker who makes the entire shoe is gone. Now the job is divided among a number of men, each a specialist in his operation on uppers, linings, or soles. He no longer needs to be a skilled shoemaker; he needs only to be able to assemble two items or run one machine. Under line-production conditions the optimum point in work specialization may be reached.

The chief advantage which this divisioning of work offers to the manufacturer is a reduced cost of labor. At the same time it is an opportunity to give employment to unskilled or semiskilled workers and thus open a much larger labor supply. Another major benefit is the ease of training employees. Workers are shown their simple operations and within a short time develop the required ability to fit into the line. This has been demonstrated many times. One company required "90 days to train operators for a certain job" before they became "highly skilled." In another case, a breech-block line for antiaircraft cannon was within a short period manned by automobile upholsterers. This ease of training is fundamentally important when changes in output or product are frequent. Still another advantage follows in the automatic elimination of the waste motions so often a part of the craftsman's work. When the time of the work cycle is reduced, the worker automatically cuts his own waste motions, for he slips into a rhythm induced by repetition and thus eliminates excess turning, eye motion, and other nonproductive movements.

[1] Personnel concerned with stores, inspection, or maintenance activities are considered in Chapters X, XII, and XIII, respectively.

## THE OPERATOR-LINE RELATIONSHIP

**Pace.**—The operator in a production line has less control over his working speed than the job-shop employee. Each worker has certain work assigned to him which must be completed in the time allotted. Otherwise, the line beyond his station, as well as other dependent lines, may be delayed. Where there is no slack in the float, the worker's pace is precisely determined when the speed of the line is established and the operations assigned. He is required to work at the same rate continuously.

It should not be inferred that line workers always work faster than job-lot men, for this is not the case. The latter may work very rapidly because of strict supervision, good shop spirit, or a wage incentive, while the line men may work below capacity because the line is slow or operations are poorly balanced. But generally speaking, the worker in flow production is paced by the line. He must be there when the piece comes to his station, and he must perform the required operation in the time allowed. This necessity of meeting the speed of the line is closely related to what has been mentioned as the *pull of the line.*

The fact that the pace of work is more directly under management's control in line production is an important one. The power which management is thus given to set the speed of the line is not to be taken lightly. Used wisely, it may maintain production at a high level. But if the pace is based on inaccurate time studies, careless estimates, or the whim of the foreman, production may increase for a time but soon be offset by other factors. Labor turnover may increase; it may be difficult to maintain quality; or sabotage may be used to slow down the line.

**Mechanization.**—Some people criticize the increasing use of line-production techniques on the ground that they reduce the worker to little more than a machine. Such judgments are too often based on impressions gained during a guided plant tour rather than on any thorough study of conditions.

These observers, however sincere, may be mistaken in attributing to the workers the same feelings which they experience in watching the operations.[1] Merely because a job looks repetitive does not mean that it is boring to the workman, nor does the fact that a machine is large mean that its tender has become but an insignificant part of it. Dubreuil points out that repetitive work was known long before the introduction of modern line-production methods; witness the handwork in the case of weaving and the makers of pins.

In this problem of mechanization, as in other aspects of human relations in industry, the attitude of the workers, their emotions, and their feelings are particularly important. In some factories the workers feel they are mere machines, while in others (where the work situation seems the same to a casual observer) they work happily, content with their jobs. An important factor in determining the workers' attitudes is the attitude of management; where operators are treated as machines, they will probably show only a mechanical interest in their work.

**Interest.**—The line employee may appear to take less interest or pride in his work, since he performs only what seems to be an insignificant part of the whole job. When a worker carries a job through from beginning to end, from raw material to complete product, he has the satisfaction that comes from the completion of a job. In modern industry, however, the complex operations and demand for specialization make this impracticable. Pride in workmanship should be encouraged in some other way, since it will improve interest, morale, and the quality of work. People seemingly make better progress when they know the importance of their operations and their relationship to the finished product. In one factory a picture of the finished assembly is hung on the wall of each department, with arrows drawn to the parts made in that department.

[1] Dubreuil, H., "Robots or Men?" Harper & Brothers, New York, 1930, pp. 106–116.
Mayo, Elton, "The Human Problems of an Industrial Civilization," The Macmillan Company, New York, 1933, pp. 35–40.

In many cases the worker can see the end of the line with the finished unit coming off. He can see the work taking form in the adjacent work stations. Though he has not the pride of making a complete unit as he might in a fixed assembly location, he does see the result of his efforts to a much greater extent than in job-lot fabrication where each operation is performed in a different department. In this connection, it is always helpful in introducing a new worker to take him down to the end of the line and show him the complete part or assembly.

Another means of increasing worker interest is through encouraging him to study and improve the method of doing his job. The production engineers should not overlook this source of operation improvement, for many ingenious procedures leading to important savings have been developed by operators.

**Fatigue.**—Much has been written about fatigue, boredom, and monotony in industrial work. It is not our purpose to discuss them at length or to consider any differences between physiological and psychological fatigue. Industrial fatigue may be influenced by such factors as length and character of work, work methods, lighting, temperature and ventilation, noise, rest pauses, nourishment, clothing, vision, or personal characteristics of the worker.

We have omitted worker attitude from this list, for it is affected by all the others. Of the many factors which influence output, worker attitude is the most significant. The viewpoint of the worker with respect to supervision, fellow-operators, shop conditions, and home seems to affect his output more than the job itself, as studies made at the Western Electric Hawthorne plant,[1] show.

Despite this fact, it must be admitted that the work on production lines is likely to be more simple, repetitive, and mechanical than that in job-lot plants. To relieve workers

[1] Roethlisberger, F. J., and Dickson, Wm. J., "Management and the Worker," Harvard University Press, Cambridge, Mass., 1939.

of the monotony of continuous work, certain steps can be taken on production lines.

*Patterns of work* can be developed, which will give a definite *rhythm* to the job. To a considerable degree rhythm can lessen fatigue. Often, workers will automatically figure out a sequence of motions when a regular routine has not been shown to them.

*Rotation of workers* from one operation to another has the advantage of increasing the operators' interest and adaptability. It facilitates upgrading and leads to better appreciation of the other employees' work. It will be limited to jobs of the same classification or pay group and to those which do not require too much instruction time. Any rotation that involves moving workers to another line has the disadvantages of breaking up social groups, causing fear of lost seniority, and destroying continuity of comfortable or familiar jobs.

*Rest periods* permit of relaxation. Singing and talking may lessen the routine aspect of repetitive line operation. Even a "line cry" or midafternoon "roar" participated in by all employees along a line has been said to offer relief.

**The Union and the Line.**—Contrary to popular opinion, labor unions today do not oppose the use of line-production methods as such. They realize that technological and economic changes cannot be prevented, and they know of too many cases in the past where unions attempting to impede such changes have lost thereby. They do oppose what they consider to be abuses of line production, such as excessive conveyor speedup and insufficient personal time.

Prior to the rise of the C.I.O., few unions showed any interest in the mass of relatively unskilled employees who worked on lines. The craft unions felt opposed to the line-production method because their members were skilled and would feel degraded if put on simplified line jobs. But today many unions seek strength from the very mass-production industries which are leaders in the techniques of line production. Such unions realize that line production offers employment to a great many unskilled workers and therefore have little regard for critics who condemn line production.

**Why Employees Like Production Lines.**—Employees feel that the production line offers them certain advantages:

*Simplicity.*—Because the jobs are not complicated, the employees have to do little thinking. Not only is learning made easy, but the requisite tempo can be quickly reached. After efficiency is attained, the job becomes more or less automatic and is no longer problematic.

*Sociability.*—Employees on a line are usually stationed near each other. While on the job, they can talk, sing, and generally become more companionable. When the pace becomes completely rhythmic, they may even feel enjoyment in the work.

*Ease of Accomplishment.*—The line employee does not need to plan or schedule his work; this is done for him. His material is brought to him without effort or responsibility on his part. He seldom is concerned with reading blueprints, judging close tolerances, or making special setups. For the average operator the production line offers the path of least resistance in his attempt to earn a living wage and attain the satisfaction of a job well done.

*Uniformity.*—The job-lot employee gets "fat," or "soft," jobs one day and difficult ones the next. If the foreman assigns him too much difficult work, he may feel that he is being discriminated against. Also, he never knows how hard he will have to work or, if on an incentive, how much he will be able to earn during any one week. The line employee usually performs the same work from day to day, knowing in advance how hard he will have to work and how much he will earn. Likewise, pressure cannot so easily be put on him for rush work without overtime. This helps to eliminate apprehension and to give the worker a sense of well-being.

*Continuity.*—In job-lot production, there are often delays between lots, time lost in getting tools, waiting while new jobs are set up, and other nonproductive delays over which the employee has no control. Even though the worker may not lose pay, interruptions are disconcerting and irritating. On a line there are seldom such interruptions, for the work can be more carefully planned and there are fewer machine change-overs. These factors give the employee greater confidence in the certainty of continuous and stabilized activity.

**Why Employees Dislike Lines.**—Employees also find certain disadvantages in line production:

*Limitation of Personal Output.*—The line employee's output is limited to that of the slowest operator in his group or to the pace of the conveyor. This is one of the chief weaknesses of line production. Regardless of a worker's ability or desire for greater production, his output and pay are often fixed. Were this employee working alone, he would be free to produce to the limit of his capacity. If his wage were based on output, a superior operator could earn more off the line.

*Restriction of Opportunities for Self-improvement.*—Employees may feel that their opportunity for advancement has lessened when they are put on a line. Since the operations require no more knowledge than that given at the time of training, any further knowledge or skill they may have seems valueless. At the same time, increased skill appears harder to obtain. A workman on job-lot production may have a different job each day and the bits of knowledge he acquires from each task may enable him to advance. Moreover, since the line is regarded as a unit, the workers themselves may not be given individual consideration or recognition.

*Decrease in Sense of Security.*—Although a line-production employee is trained at his particular job, he can be easily replaced. Frequently, foremen even prefer to train entirely new operators when changes are made in the line. Because line workers are less valuable to the company, they feel less secure. While in a sense this is due to the division of work, it results more directly from a lack of skill, and all unskilled workers may suffer this insecurity.

*Pressure of Paced Production.*—The line employee feels impelled to do his particular job at a rate which will enable him to keep pace with the rest of the line. If he slows up, he may be discharged. The embarrassment of being the bottleneck on the line also is a stimulus. Unlike the job-lot worker, he cannot work slowly for a while and later increase his speed. This constant obligation, together with the fear of being forced into an ever-faster pace by an unreasonable management, leads many workers to dislike production lines.

*Reduction in Personal Liberties.*—Because of the interdependent nature of line-production operations and the use of paced-production methods, workers have not the personal freedom that is common in job-lot plants.

## SELECTION OF LINE EMPLOYEES

**Skill.**—From the standpoint of skill it is generally believed that the semiskilled employee is the most satisfactory. Only in rare instances will a skilled craftsman be used to advantage on line work. The unskilled or semiskilled worker is more apt to be content with the simple and repetitive task. He will perform the work for which he is trained and is not so likely to question the method of doing the job or to fuss over unnecessarily good quality.

**Adaptability.**—For production lines, manufacturers are seldom interested in workers with knowledge acquired on previous jobs. To place an experienced or highly educated person on a simple line job is viewed as a waste of man power and wages, as he is quickly dissatisfied with work below his ability. Adaptability is rather to be sought. Line-production workers are seldom selected for a specific job. Usually, the aim is to secure operators with the capacity to do a number of jobs, for although the company may manufacture the same product for an extended period, changes and improvements in the lines involve frequent readjustments.

**Willingness.**—Malcontents are not unusual on production lines because of the heavy pressure for prompt output. An operator must have a temperament that is not ruffled by time compulsion. One company will not consider girls for paced-conveyor lines until they have been employed for a year, during which period their personalities are observed to see if they are suited for such work. An attitude of willingness also is important. It is sometimes company policy to ask employees if they would like to work on the line.

**Compatibility.**—That workers are much closer together and dependent on each other has been pointed out. It is good practice to select operators with congenial personalities who find it easy to get along with others in the line.

**Youth.**—Youth is another consideration. This is not alone because of the fewer personal liberties and emphasis on output. An older worker with years of experience will undoubtedly be of more value in maintenance, toolroom, relief, or supervisory work. There is a noticeable tendency to make production lines the ground-school course from which workers graduate to the many facilitating jobs which support the line and which have been discussed in other chapters.

**Training.**—The ease with which employees can be trained for line work has been indicated as a major advantage in line production. This does not mean that instruction and training of workers can be overlooked; the worker must know his job well enough to perform the correct operations and to handle the required flow of material. It does mean that adequate training for one particular task can be given in a much shorter time and that the operator is put to work sooner and at less cost. The tighter the line, the more comprehensive must be the training. A factor that makes for ease in training is the use of detail process drawings, instruction charts, or moving-picture films. These elaborate visual aids will, because of the large output, pay for themselves. Work-station assignment control, as illustrated by Fig. 99, while not training material, will definitely inform workers of the operations for which they are responsible.

Training on the line is sometimes done by supervisors or group leaders or by utility or relief operators. At the time a new line is getting under way, it may be necessary to call on other workers in the line for assistance, though the best training usually is provided by regular instructors. Obviously, someone with teaching ability who can offer practical sugges-

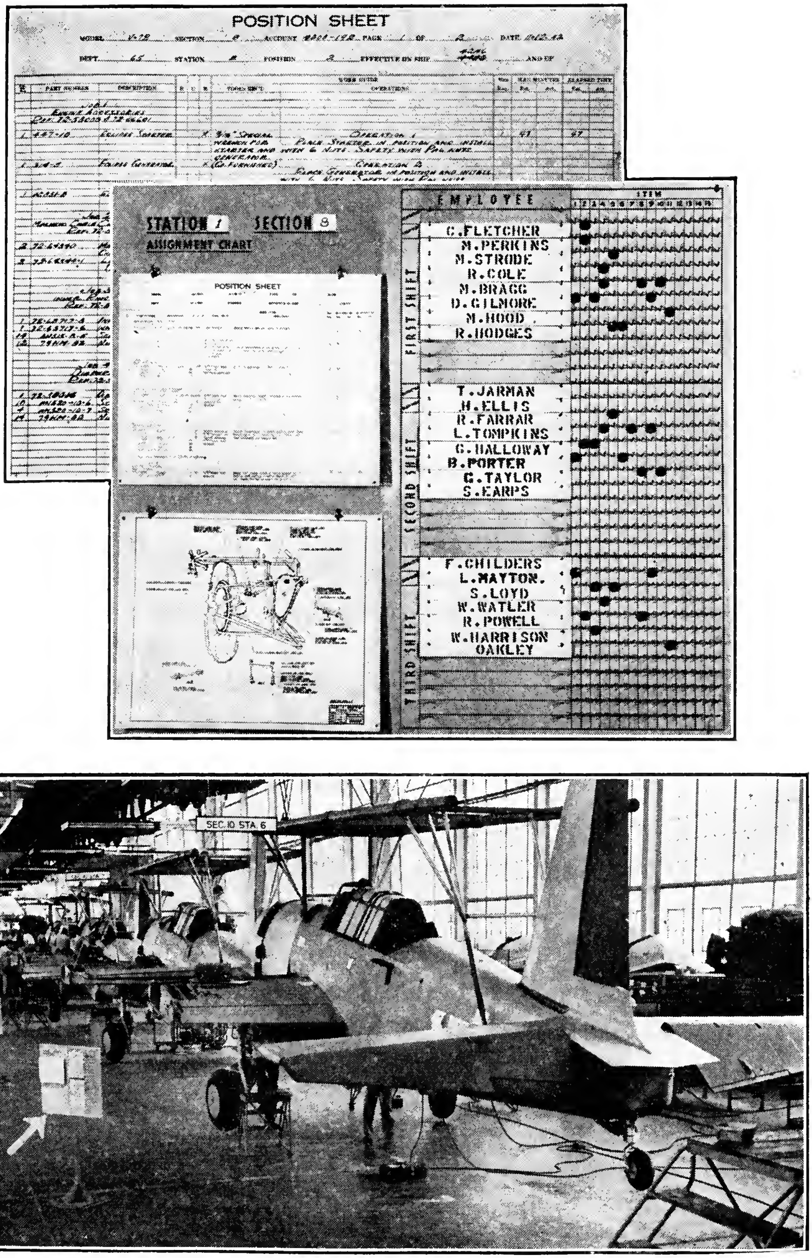



FIG. 99.—Job assignments are clearly posted on a stand beside this assembly line. Close-up view of this assignment chart shows exactly which operators are responsible for installing each item. The position sheet and the drawing give the detail for every operation in the particular station. The planes on this line are suspended from an overhead conveyor. (*From American Machinist.*)

tions with respect to the particular line, material, or group of operators is desirable.

Many foremen prefer green workers whose training they can supervise. Older, more experienced operators have personal ideas which may have to be "unlearned." They are less willing to be instructed or to perform as instructed. Preconceptions regarding the number of units which constitute a day's work also are found to be troublesome. One company executive stated that he would shortly have 30,000 men at work in a brand-new plant, and that he hoped none of the production-line workers had ever seen a machine before.

Personnel men, therefore, should recognize that the employees have certain likes and dislikes for line production, and that the breakdown of operations and their placement in a line also have significance in personnel management. In considering a change to line production, the personnel executive should carefully weigh these considerations.

## ASSURING CONTINUITY OF OPERATION

Of particular concern in line production is the absent operator. Absence of a worker in job-lot layout has little effect on other operations or on the total output. In a line, however, a missing operator from a key job may shut down production unless special precautions are taken. Here, as in any interruption in the flow of material, the problem is found to be more acute on fast, tightly scheduled assembly lines. Fabricating lines carry larger floats, and the operators have more control over their own time.

Tardiness also can disable production schedules, and workers may often have to leave the line on account of accidents or sudden illness. Provisions should also be made to allow the worker to leave the line for personal needs or for rest. The magnitude of the problem is realized at one plant where less than 12 operators left their work early in order to attend a bowling meet, but their tasks were of such key importance that practically the whole plant had to be shut down.

Provisions to take care of such absences, whether unforeseen or anticipated, may be made in a number of ways.

**Relief and Utility Operators.**—Workmen who are specifically assigned to substitute for regular operators along the line are termed *relief operators.* They may rove along the line at random, covering a certain group of operations, or they may be on a fixed schedule, relieving each operator periodically for an established period. In one plant, a girl is employed to give each of the other girls on a section of the line a rest period of 10 min. in the morning and again in the afternoon. The relief operator begins at one end of the line and releases each operator for 10 min. She progresses down the line until every girl has been relieved. Under this system an operator can leave the line only when her place is taken by the relief operator, so that not more than one worker will be away from the production area at any time. This avoids congestion and a tendency to linger in rest rooms.

Production-line plants generally have utility or spare operators to handle long or irregular absences. Sometimes these are also group leaders or instructors. These operators may be kept on hand in each department, or they may be held as a pool to substitute on any line.

Job-setters, instructors, and foremen have all been used to fill in for short periods of time. In other cases, maintenance men, stock handlers, and inspectors have been successfully employed as substitutes. One company uses salvage men to replace absent workers, as the transfer seldom affects critical salvage operations. The shoe industry sometimes makes use of "irregulars." Often employees who have left the company because of age or home conditions are willing to work part time. They feel there is a certain amount of prestige in having a job that does not call them before nine o'clock in the morning or require them to stay later than three.

Relief operators are usually busy along the line only a portion of the morning and afternoon, and the number of utility men seldom evenly matches the number of absentees. When these men are not occupied on the line, they may be assigned to individual jobs that one operator can perform, to miscellaneous bench work such as burring, or to arrangement of stock and supplies. They can assist on the bottleneck operations should there be room to build up the float. One company keeps its utility crews busy on odd-lot orders for replacement parts.

**Transfers and Shifts of Workers.**—When utility or spare operators are not maintained, it is frequently possible to obtain "loaned labor" from another production department. Such a transfer is difficult for the workers and foremen, often resulting in a shift of the poorest workman and thus slowing down the line. Moreover, it raises the question of skill difference and variations in training. However, these transfers of workmen have been managed satisfactorily in some instances. If possible, the transferred workman should have at some previous time performed the particular task.

Frequently, it is possible to redistribute the workers along their line to care for the operations of the absent worker. Particularly where there is group incentive, it is often feasible to let the group handle the job and temporarily to make their own balance. Supervisors will, of course, help in moving the men about most expeditiously. Within a certain section of the line, workers may become familiar with the operations of others and can readily be shifted. One company making electrical instruments operates a number of short assembly lines and reports that each operator can do any job on his line. This is commonly the case on simple work where there is rotation of jobs or where the foreman has taken care to train his men on each operation. Where questions of skill difference arise in the shift of workers to other jobs, the foreman should discover whether each man can perform the alternate task.

Another plant found it easy to move operators from subassembly lines to the main line. Taking an operator from subassembly work where there was considerable float did not delay the flow into the main line. Where subassemblies are performed as bench work beside the line or on a more or less job-lot basis, the operators are more readily shifted. Many times, workers are transferred from repair or packing operations to temporary line activities.

**Rest Periods.**—Rest periods are a preventive means of reducing absence from the line. At definite periods during the day everyone stops work and leaves the line. This arrangement simply organizes the habits of the workers so that they all take time out simultaneously. During these periods the line is completely shut down; but the loss is less than appears, as the workers should not have to leave their stations thereafter.

When the operation time is long and the work moves slowly, it is sometimes possible for any employee, by accelerating his pace, to build up a surplus or temporary bank. With this reserve, he may then take a brief time off. Naturally, a bank or large float between operations permits workers to leave an unpaced line at will.

Other methods of reducing problems caused by workers away from the line take the form of attendance bonuses or tardiness penalties, adequate training of extra operators, an early check by the foreman of tardy or absent workers, social pressure from others in the group, oversized floats, duplicate lines, and overtime work to make up for decreased production, though this last procedure is expensive and hardly a protection. When a large proportion of the workers on a given line are absent, it may be easier to shut down the line for the day and transfer the operators to other work, provided there are no dependent lines and that production schedules will allow.

**Obstacles to Continuity.**—All of the above systems for assuring continuity have certain disadvantages. If the fill-in operator is not efficient, the rest of the employees may complain because their line speed is reduced or certain operations are delayed. It may even be necessary to replace a regular operator by two substitutes. On the other hand, the substitute worker usually is more skilled and versatile (if an instructor or regular utility man, for example) and is paid at a higher rate, thereby increasing the cost on the job. Rest periods mean less total operating time and offer no protection against workers absent from the plant. Transfers involving difference in wage rates are more difficult for the time office or pay-roll groups.

Job classification likewise raises many problems in the shifting of workers from one station to another. Operators in one classification are not supposed to do the work of those in another. For example, milling-machine operators are not expected to operate lathes. Such classifications have limited output, for at times a worker could otherwise assist on adjacent operations and thus speed production were it not for his

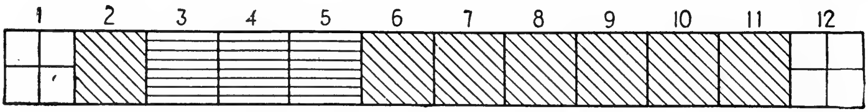



**Fig. 100.**—This worker skill chart is one method of helping to transfer operators. It is a diagrammatic method of indicating operations on the line that require approximately the same kind and level of skill. The worker on Operation 2, for instance, may be shifted to 9, 3 to 5, and 1 to 12. (*From American Machinist.*)

difference in classification. From a quality and safety standpoint, however, job classifications are a definite protection, for the untrained worker may spoil work or break expensive equipment. Again, classifications serve importantly in facilitating over-all hirings, transferring and promoting. Where workers regularly alternate between jobs of different classifications, they are generally paid at the higher rate. When all the workers on the line are in the same classification, this is, of course, no problem, though the foreman may still use his knowledge of the abilities of his various workers. Here he may be assisted by some device similar to that shown in Fig. 100.

## INCENTIVES

Many production lines use straight hourly or daily rates of pay satisfactorily. On a line paced by a powered conveyor, incentives have little productive significance (note the exception in Fig. 101) because changes in the effort of the employees cannot vary their output. Here a straight time wage can be paid with good results, though if there are incentives for the job-lot work in the same plant, wages on the paced line may have to be raised so that these workers can earn an equivalent "take-home." Nevertheless, employees who fear that the conveyor speed will be stepped up usually prefer some kind of incentive payment system. In order to prevent argument

Fig. 101.—This rubber-shoe assembly line is a paced production conveyor with a wage incentive. The speed of the line is as fast as the operators wish it to be set, but any worker can stop the line momentarily by merely pulling the cord above the line in the event of minor delays in her operation. The line may restart automatically after several sec. or may be set to begin again only after one of the operators again pulls the cord. (*Courtesy of United States Rubber Company.*)

over the speed of the line, the conveyor speed control is sometimes locked and opened only when a representative of the workers is present. In other cases, union agreements definitely state at what speed the conveyor shall operate.

The day rate has proved satisfactory for other reasons. The desire to keep pace with other workers in the line is very strong, and a banked-up float will generally point out the slow operator. The rate of flow of contributory or succeeding lines is an impelling force for the line as a whole. Furthermore, an operator- or line-performance rating can be used to measure the ability of individuals or the group to meet the desired rate of production. The foreman may be held for meeting the output in the time allowed or may receive a bonus based on the efficiency of his line. Balancing information such as that shown in Fig. 102 may be used to help him control his man power.

Where the speed of the workers can influence the rate of production, some form of incentive will generally increase output. Individual incentives, however, have no great value in line production. Often, although there is no conveyor pacing, each operator is limited by the speed of others in the line. With an individual incentive each operator will work entirely for himself, making little effort to help others.

**Group Incentive.**—When the number of units coming off the end of the line is the basis for pay, the incentive acts for the whole group of workers. Under this system, if any employee reduces pace, he is lessening production and earnings not only for himself but for everyone else in the line. For this reason social pressure for cooperation tends to be greater. Workers may of themselves help out on bottleneck operations in order to increase their own earnings. As a result more reliance can be put on the line to work out its own balancing, to break in the new operators, and to notify foremen of any delays for lack of stock or unadjusted machines. Group incentives generally save time-keeping and pay-roll costs. Fundamentally, since the line is scheduled as a unit and works as a unit, a group wage based upon the final output of this unit is usually more satisfactory.

Gang piece rate and group bonus are the types of group incentive most commonly used on production lines. They are both based on the productivity of the line and there is little distinction between them. The workers may or may not receive the same base rate, but each is paid his share of the amount earned by the group.

There are several drawbacks to group incentive systems. They do not allow recognition of individual speed or skill to the same degree as an individual incentive, nor is pay entirely

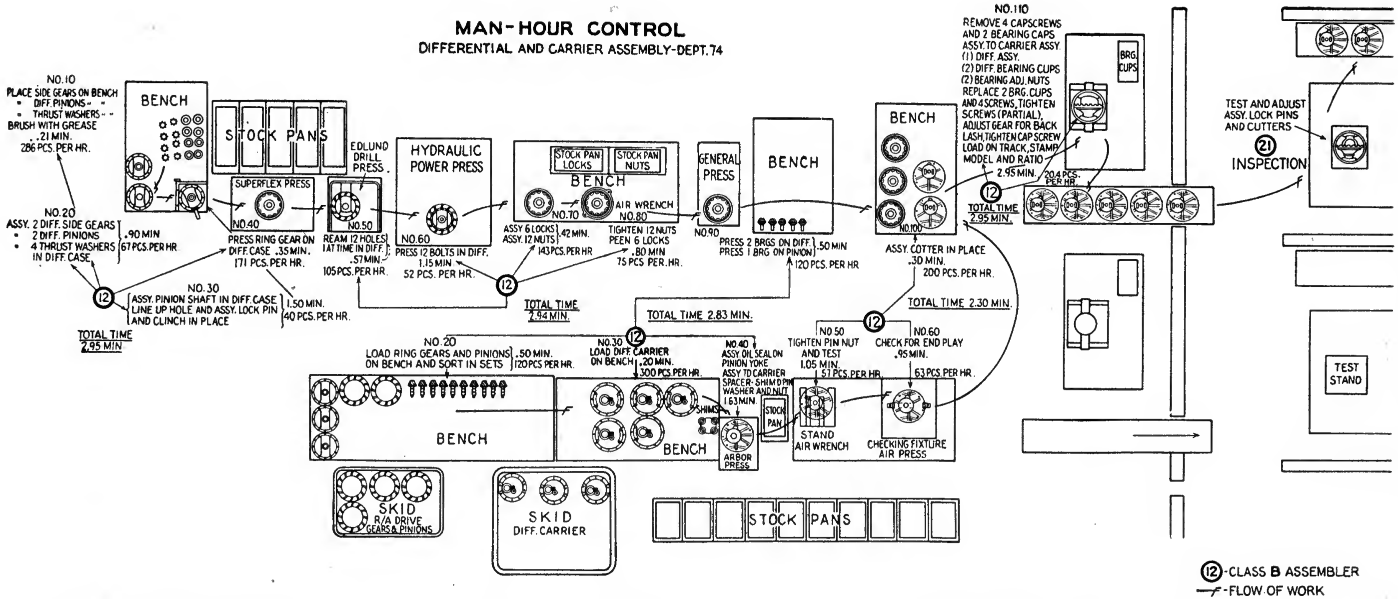



FIG. 102.—Blueprints similar to this show foremen how to balance their lines most economically. They indicate the time each man is allowed to perform his operation. With the aid of this and some experimentation, a foreman may be able to turn out an even greater number of assemblies in less than the allowed time by reducing the inherent delay, or idle balancing time. (*Courtesy of Chrysler Corporation.*)

commensurate with the effort of the individual. When the line is held up for one reason or another, several operators may be delayed, so that the group as a whole loses. Moreover, if group leaders and supervisors are included, care should be taken that they do not receive overtime and thus be tempted to increase the total hours of work without increasing the output. The size of the group plays a decisive part, group incentives working best where the group is not too large or scattered. To be sure, any incentive system puts increased stress upon quantity rather than quality. Usually, this hazard is met by including in the count only the acceptable pieces produced.

When an incentive system is used, arrangements to provide a day rate or "average earnings" should be made for delays, bad tools, poor material, and the like. When dies are wrongly set, the operator cannot produce acceptable work. When a new employee is put into a line, his output will be low, even though he is thoroughly trained to do the job. A special day rate for the new man is necessary if he is to receive a reasonable wage while learning. A bonus may also be paid to maintain the wages of the rest of the group and forestall any feelings of unfair treatment or of resentment toward the new employee.

Many plants have a spread, or difference, in the rate of wages paid to workmen on the same line, even between those doing the same type of work. Generally, these differences in rate rest upon time with the company or on some form of merit rating. Many plants raise a new worker to the working rate or to the top rate as soon as he attains the speed of the line and produces good work. This system offers an incentive for the new worker to learn. However, since there is never perfect balance, this operator may break in on a "light" operation and come up to speed faster than another operator who started on a "tighter" operation. This variation has often been a point of contention.

**Calculating Line Output.**—The calculation of line productivity is under the direction of the production-control group or the inspection department. The responsibility of notifying the production-control and pay-roll departments should be vested in but one individual. For purposes of pay determination and production control it is necessary to divide lengthy lines not on paced conveyors into *count points,* or *break points.* For example, on a certain line where there are three groups of operations—roughers, finishers, and polishers—the count points would be set up at the end of each group.

The locations of these count points vary with the type of line. They are determined largely by the places at which the best or easiest count can be made without the necessity of building up a large bank. Again, it is desirable to keep certain types of operations together. Also, the smaller the group, the more effective is the incentive. Moreover, the counts may have to consider the work of more than one shift, and it must be recognized that sometimes one shift can absorb the credit established by a previous shift.

Potential credits accumulate at certain points in the line, frequently making a weekly inventory of the group or line necessary to ensure proper current credit. If a bank of parts has been finished but not yet inspected, it would seem desirable to give the group credit for this amount during the week when the parts are produced. In other cases a score is taken of the entire float each day and credit is given for the percentage finished on each part. On a 10-station line this would be one-tenth times the number of units beyond Station 1 but not past Station 2, etc. While this may seem unnecessarily precise, it controls the size of the float and may disclose the presence of unreported banks.

Count points may be of value in a situation where long, slow lines are changed over to other work. During the time such a line is getting into production, a temporary day rate is paid. At the end of the model run, however, when the last units are going over the line, the operators at the head complete their work and take time off while equipment is being changed over for the new sequence. Operators at the end of the line, who are turning out their regular daily production, may thus receive twice the normal pay inasmuch as there are now half as many workers among whom the same final count is divided. To be fair, this payment should be distributed to all the workers.

There are various methods of counting processed work. Mechanical counters can be placed on machines. Tickets can move along with the work and stubs be torn off at the count points. The greatest accuracy for an individual part lies in an identification which can move with the work and be checked off or punched as operations are performed. But where large banks and storage conveyors are used, such parts can become lost in the system unless care is taken to circulate stock in the banks.

## PART IV

## DIVERSIFICATION IN LINE PRODUCTION

## CHAPTER XV

## FLEXIBILITY

Line production offers opportunity for the introduction of far more flexibility than is generally assumed. Again, its procedures may be considerably modified in order to adjust the particular operating conditions or requirements. Such activities provide unusual opportunities for ingenuity and account for the wide variety of production lines found in specialized processes. Part IV of the text indicates the extent to which such diversifications are possible in line-production installation and operation.

Producing a standardized item at a given rate of output by the method of line production for an extended period of time is relatively easy, for under these circumstances the line can be precisely established to fit the requirements. But in the majority of instances these given conditions are likely to be temporary, for manufacturing is an ever-changing activity. Improvements in the product cause alterations in design. Changes in product demand as reflected in sales alter the output of the line and the rate of production. Improvements in the processes result in changes in equipment and in layout. There is always the possibility that the product may be discontinued and a completely different item produced. The manager who is operating on a production-line basis must be able to meet these variations.

Probably the most frequent reason why manufacturers do not convert to line production is the fear that they may shortly have to change their new arrangements before the profit from reduced operating expense has accumulated sufficiently to cover the cost of installation. The expenditures for such change must be looked upon as an investment rather than a loss. Along with line-production methods, manufacturers need to adopt an attitude which incorporates flexibility and acceptance of change as a part of routine improvement. The degree of flexibility required can be estimated ahead of time in most cases and allowances made accordingly, but where this is not possible, a willingness to risk certain funds on a new layout may reflect sound business policy.

## FLEXIBILITY IN DESIGN

A reasonably standardized product is one of the prerequisites of line production, and when every unit is identical, this type of operation succeeds to the greatest extent. Yet line production is not necessarily so limited. In automobile plants, where line production has perhaps reached its most advanced stage, hundreds of different units are produced over the same line. One automotive company can build 18,000 different car combinations on its assembly line. In its truck production this figure is much larger. Another company making a variety of electric motors builds each motor to order. These are partly fabricated and assembled on production lines with the aid of traveling instruction sheets. The M-5 military tanks and M-8 tank destroyers were built on the same line at the same time. Shoes may be made in many sizes, on a single line installation.

Such permissible variety in products is in reality based upon the use of standardized parts. In the case of the automotive company, choice is allowed in certain standard parts and in the color, trim, and upholstery options. The electric motors are built in several basic sizes with customer choice in only a limited number of specifications. Where there is little technical difficulty in the design of the product or in the machinery used, the entire product may change from day to day. Changing the label or the color of the ingredients in an ink-bottling line is a relatively simple procedure. In any plant the degree to which the "specials" can be combined for production on one line will definitely affect the extent of line production.

**Changes in Design.**—Process or methods engineers, time-study men, tool and trouble men should constantly be alert to the possibility of improvements in methods or processes. Yet such alterations, if too frequent, create a feeling of insecurity. Sometimes lines are set up for so short a period of time that methods study is not practical except in the initial processing and organizing of the job.

Change orders involving design are sources of inconvenience in quantity production. Changes in design create obsolete parts, interrupt continuity of flow, alter equipment, upset line balance, and in general play havoc with quality of workmanship and morale of workers. Such changes may be only minor or may be so fundamental that they necessitate rearranging whole sections of the line. While the necessity for constant improvement is recognized, the privilege of a customer to change designs at will demands a flexibility that deters many manufacturers from line production.

The *freezing of design* is the accepted way in which the disadvantages of change are lessened. At the beginning of production, design and materials are usually standardized to the extent that they cannot be changed during the run unless absolutely necessary. Many companies have established 5- or 6-year freezes in design fundamentals, so that, while there may be minor changes each year, fundamental design alterations occur only after a period of years. Where changes are frequent, the design is frozen for a specific number of completed units. During the manufacture of this block, or lot, no changes are permitted. Fabricated parts are handled in job lots based on the size of the block, so that an enlarged bank which may become obsolete is not permitted to accumulate. All changes are made when production on the next block of parts begins. This is a systematic way of handling a complicated and confusing problem.

Another method is to maintain an *uninterrupted but incomplete line*, at the end of which all repair and experimental work is performed and all modifications made. The modification centers set up by the Armed Services make all alterations that cannot be immediately handled on the production line, thus leaving the manufacturer free to produce a reasonably standardized product. All changes are allowed to accumulate until their desirability is definitely proved and until their inclusion in the production line can be conveniently made. All changes that are necessary then become effective at a given time. This procedure is similar to the special painting of motor-truck fleets off the line.

Change orders are generally duplicated and sent to all parties concerned, notifying them of the nature of the change and of the time it is to take effect. Where design is involved, the engineering-change notice acts as a new release. Where changes from the standard design are only temporary, a substitution notice may be issued with the approval of the chief engineer. If, for example, a specified type of steel is not available, another kind can be used for a temporary period.

The production, or industrial, engineer in charge of the product ordinarily follows up engineering changes to make sure that they take effect at the time specified. Changes that have not yet reached the formal stage can be anticipated by the issuing of advance notices. Such preliminary contacts sometimes make it possible to work several weeks ahead of engineering change orders.

## FLEXIBILITY OF OUTPUT

One of the biggest problems in line production is caused by a fluctuating demand that is sometimes seasonal but often entirely unpredictable. In such event, it is necessary to take care of these irregularities as they appear and to prepare for them by allowing sufficient flexibility in the line.

Perhaps the easiest way to handle changes in the production schedule is by *altering the operating time*. A company may run certain lines overtime or with extra shifts, or it may cut back others to 6 hours per day or 4 days per week. This procedure is usually less difficult than to rearrange the operators and equipment in an already balanced line.

Because of the mobility of individual operators, *changing the number of workers* on the line is a means of compensating for fluctuations in output. A change in the combination of operations must inevitably accompany such a change in the number of operators. If the schedule is to be reduced by half and there are ten operators in the line, five of these can be transferred. Each of the remaining five is now assigned two operations. Many plants control their line "population" in direct relation to the rate of production scheduled, leaving to the foreman the problem of balance.

Where the number of workmen on the line is changed, there must also be *change in the speed of the line* or *in the spacing of units.* In the above case, with each worker covering two operations, the speed of the line will be cut by half so that the operator will have time to work on every unit. Variable speed drives on powered conveyors are essential for such changes. Again, the speed of the line may remain the same, but the space between units will be doubled by loading every other fixture. Workers move along the line, each covering two stations; but on finishing their cycle, they return and start on the next unit without skipping any work. This latter course is followed when there is fixed equipment in each station. Spacing the parts, of course, decreases the float on the line.

Another method of handling a change in number of workers on the line is *to spread workers irregularly along the line.* For example, with production reduced, all operators may work the first five stations in the morning and the second five in the afternoon. This device is not unlike that of making use of duplicate lines and allows considerable flexibility. Skilled operators may also spread themselves along a number of stations to assist present workers. Each extra operator develops a large bank by helping at one station; then he moves on into the next station and works on the same parts while regular operators continue their regular output.

It is also possible *to combine two or more parts* on the same line. Service orders, spare parts, or special jobs may be combined with regular runs of small volume in order to build up a volume that will justify using a line. One producer puts 29 different pistons over the same line with very little adjustment of fixtures and tools as a result of combining service parts. Combinations of units with slight diversity, only in the color of paint, for instance, meet the variations in sales demand without upsetting the line. Where there are special, small-order amounts, it is sometimes expedient to combine them with a regular item being made on a production line. Here it may be necessary to run through the main product and then to clear the line and bank the parts, allowing the special lot to run over the line-production setup. Without the main production, this small job could not be handled at such a reduced cost, because it alone could not pay for the establishment of the production line.

Still another way to care for flexibility in output is *to leave room for expansion* when the line is set up. This is accomplished by leaving a 10 to 20 per cent allowance in calculating the figures for line capacity. This is essentially a safety measure. It is possible, further, to leave greater space between units on an assembly line. Then, without changing the time on the line, the work units can be moved closer together. This will mean relocation of work-station space, a different breakdown of operations, and addition of more workers. But with the same line speed more units can be produced. To extend the line and to add duplicate lines are other devices in this category.

Actually, fluctuations in schedule can be handled more readily on a line than in a job-order plant. With line production only one department need be adjusted, while in the job-lot plant changes in schedule affect every department through which the product passes. Planning and supervision of overtime, extra operators, and rescheduled orders for each department are a more complicated problem than that of dealing with one line or system of lines. Production output may be increased immediately on the line by speeding up the line as a unit; in the job-order plant a number of different workplaces have to be increased by an equal amount.

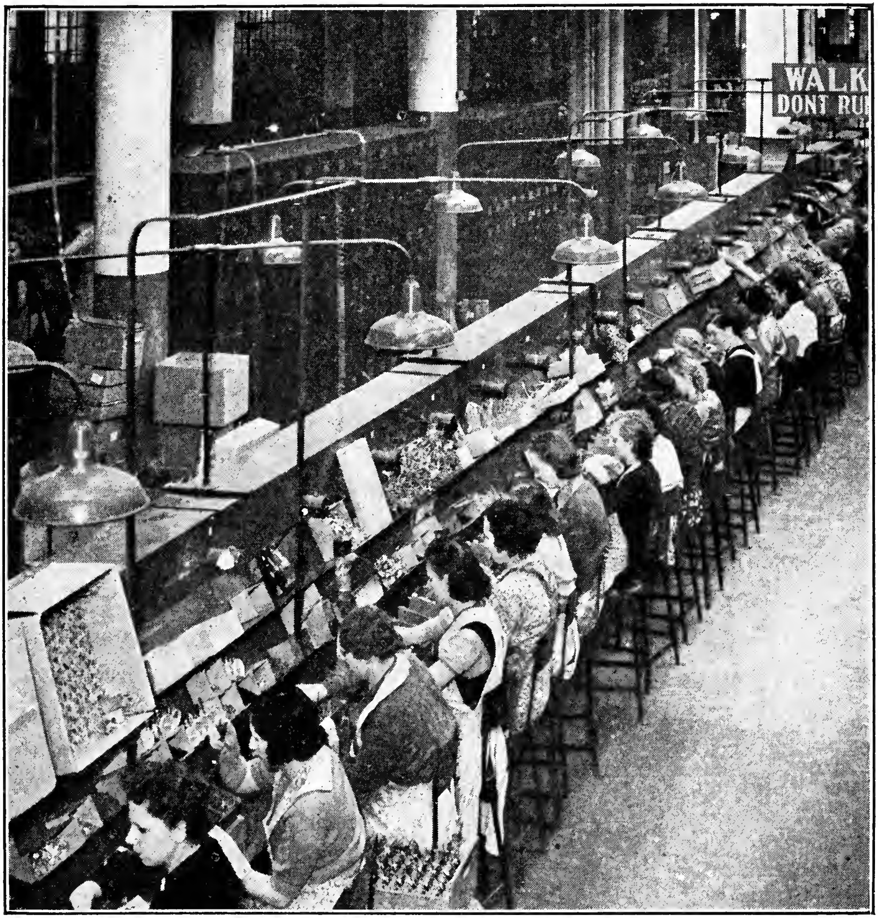



Fig. 103.—This assembly line is made up of a number of portable, standard-size workbenches and can easily be rearranged for a different layout or for new products. (*Courtesy of Zenith Radio Corporation.*)

## FLEXIBILITY IN LAYOUT

Flexibility in layout is attained largely through equipment which can be moved easily. The installation of line production is often limited by overhead line shafting in the plant or by elaborate machine foundations ineffective for other purposes. Sometimes all the equipment in certain departments is fixed into a central piping system or a central chip- or dust-collecting system. These make alterations expensive and frequently impossible, and since they are definite limitations to easy and speedy rearrangement, they are seldom found in plants that require flexible production lines. Individual drives, individual cooling systems, and everything that goes to make a *self-contained machine* are advisable if flexibility is to be attained. Where it is not possible to have a completely self-sufficient machine or work area, outlets from the central system must be readily accessible throughout the plant. Electric outlets can be placed as frequently as every 2 ft. Compressed air, water, steam lines, and the like may be piped throughout the plant so that they will be available within any floor-space area.

*Mobile equipment* may allow flexibility in the work area without requiring changes of layout. Overhead tools may be suspended so that they can be used in a section of the line rather than in but one station. In one line assembling engines the small parts and workmen's tools were placed on portable racks supported from an overhead monorail. These were moved along by the workman as he, in turn, moved with the engine. In an aircraft plant, a drill jig was mounted on wheels, so that it could be attached to the fixture and travel with the work while the holes were being drilled. Such mobility of equipment is of great assistance on continuously moving lines or on those with fluctuating rates of production.

*Standard-size assembly benches* are used by many plants to obtain flexibility in layout. These can be attached end to end as in Fig. 103, to make an assembly table of any length and can be easily rearranged whenever the line is changed over. One company assembled large rubber boats on a belt conveyor covering just such a combination of simple benches. In other cases, standard sections of conveyors can be hooked together in a variety of arrangements. Again, different-shaped lines can be assembled with standard machines by varying the conveyors which connect them, as seen in Fig. 104.

Flexibility in layout is greatly aided by *skillful techniques of moving equipment.* Trained millwrights, maintenance men, and job setters working with the proper tools can often care

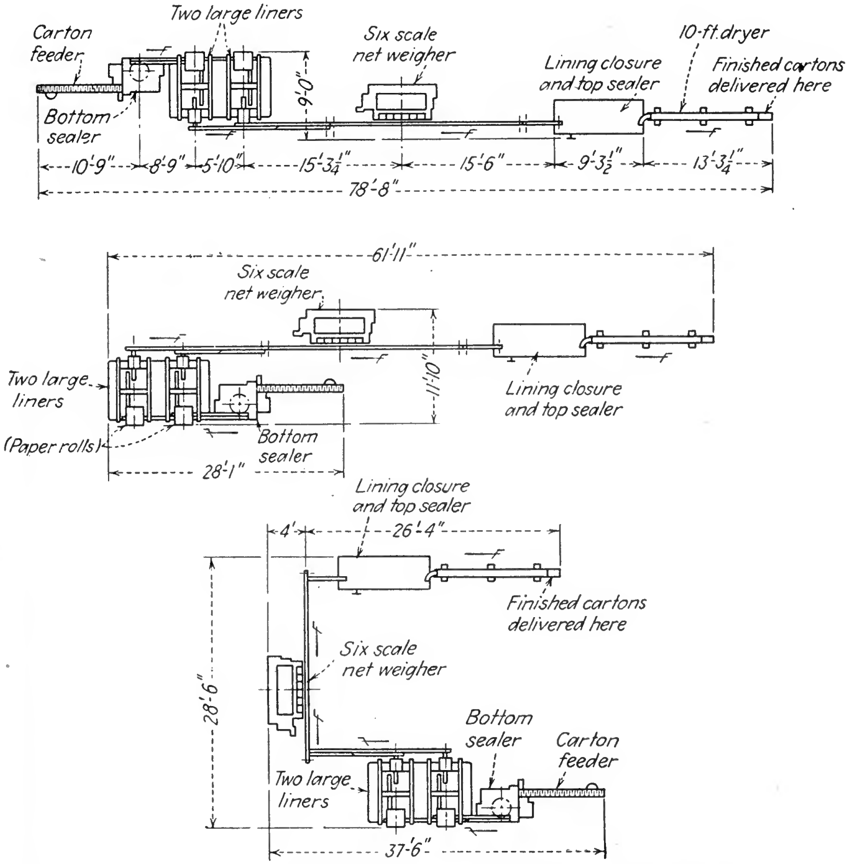



FIG. 104.—Here are three standard layouts for weighing and filling almost any dry, free-flowing material. All equipment is adjustable for different package sizes. Equipment manufacturers can in this way sell a standard packaging line and layout to fit almost any plant's conditions. Any other combination of this or other equipment may be obtained by an easy adjustment of the conveyor connections. (*Courtesy of Pneumatic Scale Corporation.*)

for extensive changes in layout with surprising effectiveness. Such alterations do not necessarily call for many expensive facilities which are seldom used. It is more than likely that the machinery can be dragged to the new location on a simple sheet-metal skid.

**Flexibility in the Float.**—Closely related and almost a part of layout flexibility is the problem of flexibility in the size, location, and sequence of the float. Many times, it is possible to carry parts through a number of stations as a lot and yet have them intermixed with different pieces during the remainder of the operations. For example, in one installation, the conveyor split into three branches, and as a lot of a certain part came through the previous operations, it was banked on

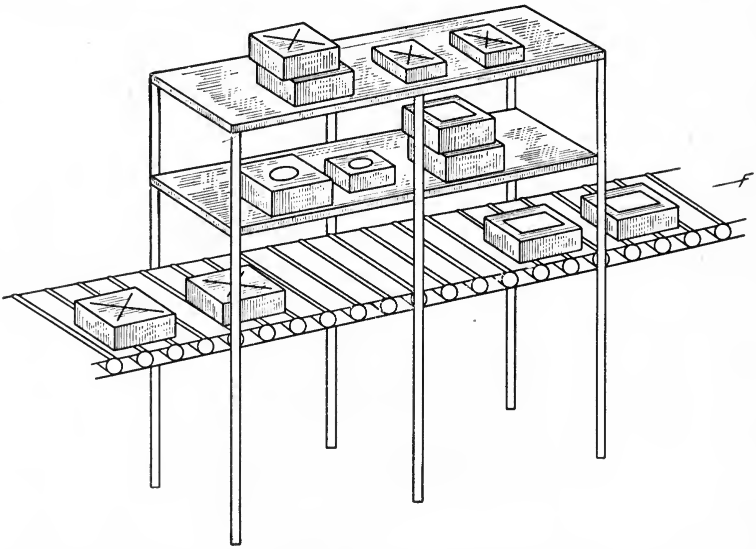


FIG. 105.—This storage rack along the line allows flexibility in the float as to both quantity and changes in the sequence of parts.

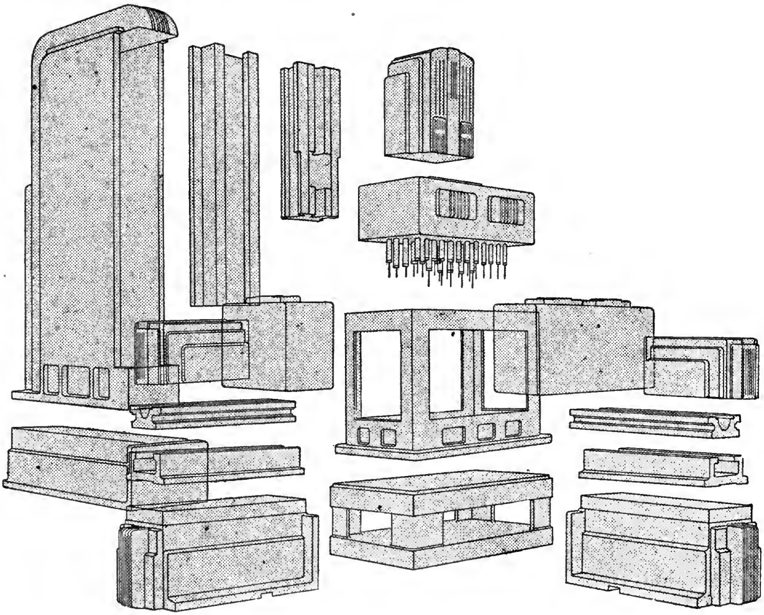
one of the sidings. As any one of the three parts was needed in subsequent operations, it could be drawn from the proper conveyor branch. A similar device is that of overhead racks placed above the conveyor line, as shown in Fig. 105. These racks require less floor space than sidings, but they involve more handling of the material. By maintaining a bank on the shelf above the line, it is also possible to by-pass such parts and rush other orders through. This arrangement allows flexibility in line time and delivery dates. It also permits the accumulation of banks so that a number of subsequent operations can be performed by lot in the event that previous operations are done individually. A sequence of several operations may sometimes be performed on a siding of the line, and special operations on nonstandard products can be performed on shunt lines alongside.

## FLEXIBILITY IN EQUIPMENT

The machinery with the greatest flexibility for handling a wide variety of work is the universal, or general-purpose, type of equipment found frequently in the job shop. This type of equipment can also be used in the line, but it is generally fitted with special tooling or gadgets to make it better suited to the one product; thereby the operation is speeded up, and the work is made easier for the operator. If this equipment cannot hold the speed of the line, a special-purpose machine is indicated. Since specialized machinery does not accommodate itself to changes in design or product, its use is desirable only if it will pay for itself during the expected run of the product.

In metalworking, there are three ways by which both specialization and flexibility in equipment can be attained. The first is by the use of a *universal machine fitted with special tooling*. Special adaptations are introduced, enabling the machine to perform a particular operation with greater ease and speed while remaining readily convertible to other work. The *unit-type machine* illustrated in Fig. 106 is similar and offers similar economic advantages. This equipment is constructed of a number of standard units put together to function as a special-purpose machine; yet it is easily rebuilt or changed to accommodate modifications in design. Such equipment is amortized over a longer period than special machinery. Again, there are many varieties of *special-purpose facilities with universal or adjustable work-holding devices* in order to accommodate a number of different products. On conveyors, for example, hooks can be designed not only for easy handling, but for carrying a wide range of parts. The conveyor in Fig. 107 may handle any length of propeller blade called for.

Because of improvements and frequent changes in specialized equipment, many companies maintain a *tool and machine*



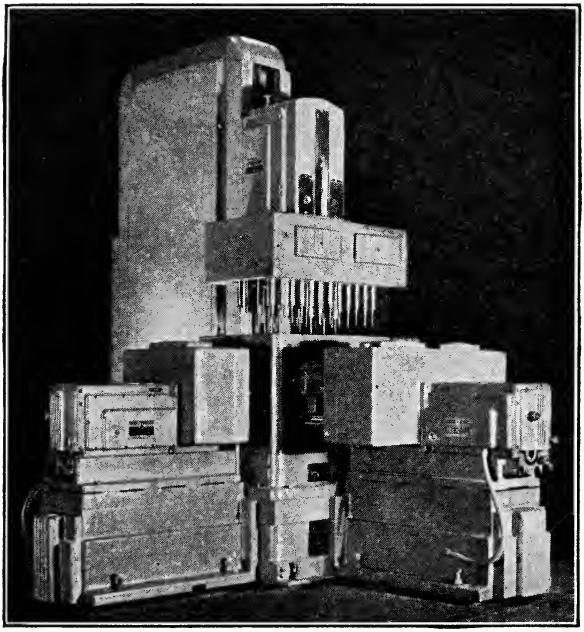


FIG. 106.—Unit-type machine showing how a machine for a special purpose can be made from a number of standard units. (*Courtesy of The Ingersoll Milling Machine Company.*)

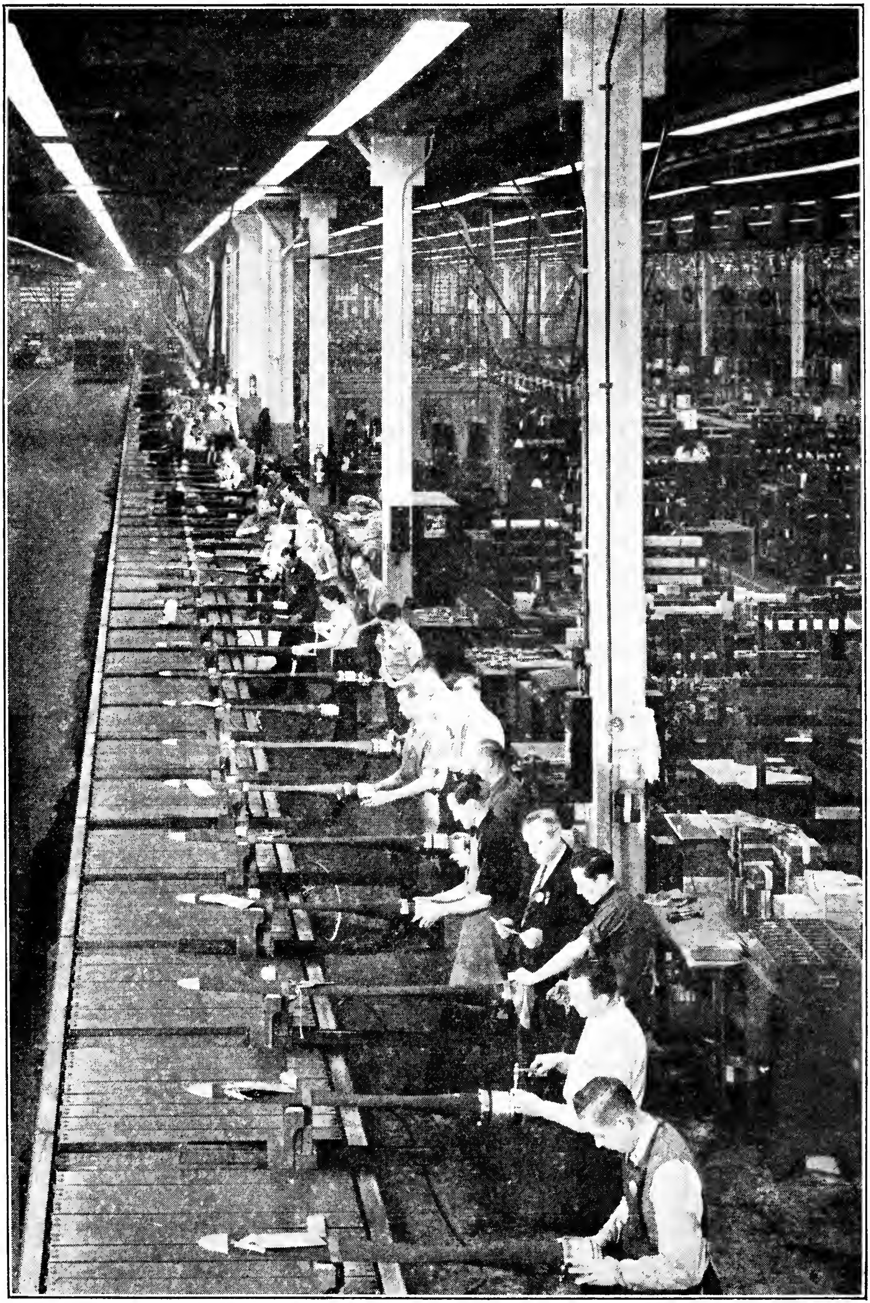


FIG. 107.—Assembly line for propeller blades of different lengths. (*From Machinery.*)

*clearinghouse.* All the facilities discarded by one department are collected at, or reported to, a central storage area or pool and there drawn upon by other departments. Inventory data on this equipment are supplied periodically to the production engineers to aid them in the selection of equipment that is already on hand and available for use.

## CHANGEOVER

Changeover of the entire line is not unusual. Complete rearrangement may be necessary in conversion from job-lot to line production, in change from the manufacture of one product to another, or at the time of model alteration. It seems obvious that the greater the degree of change in the product, the greater will be the problems of conversion.

It is customary to make the changeover at a *low point in production*, so that the line can be shut down. Lines can be rearranged at night or over the week end. Simple lines, where units are hand assembled on a belt conveyor without the use of fixtures, may be altered almost momentarily. When a changeover involves the entire plant, it is usually made during the slack production season. Banks can be increased or production scheduled irregularly to allow for changeover. There has been mention earlier of the careful scheduling that may be necessary to install equipment on time and to allow time to process the materials from the raw state into form for use on the particular line. In many instances, the run of raw material and subassemblies on an old model will be closed down several weeks before the final assembly lines complete the model run. Thus the fabricating shops and feeding lines will have an opportunity to convert to the new model and have components ready for the starting of the final assembly line.

If a company is not entirely familiar with the new product it is making, gradual changeover can be accomplished by building a sort of *mixture model.* This was done at one of the tank arsenals where a special design was made experimentally at the time of converting from one model to another. By this method the complete plant was changed over without shutting down the lines, a feat which is expensive and rarely practical. Even in automobile production a minimum of 2 weeks' shutdown is allowed for conversion to a new model.

Where *duplicate lines* are producing the same items within a plant, there is opportunity for greater flexibility. Since production can be discontinued on one line while the other line is still producing, a more gradual conversion is possible. Work can be shifted over as the converted line accelerates. Later, the second line can be likewise altered. Some plants follow this practice by using one line entirely for experimental purposes and for the ironing out of minor defects. These improvements are later installed in the main, fast-moving line.

**Changeover Personnel.**—The workmen themselves may make the changeover. More often they assist the setup and maintenance men or care for stock and work-area cleanup. Frequently, operators are given vacations during the downtime. In some plants, when employees are used to help with the changeover, their work includes pouring concrete or re-laying floors. In the event that the conversion requires more skilled labor than is available in the plant, it will be necessary to call upon outside contractors to assist in rearrangement and installation.

In plants with machining operations, it is customary for the utility men and group leaders to help with the work in the toolroom or machine-repair or maintenance shop during the model change. They thus gain experience in setting up a line and become familiar with tools and equipment. More important, the employees in the nonproductive departments learn how production desires the work to be set up.

**Restarting the Line.**—Where the installation is delayed or where it takes considerable time to remove technical difficulties and to tune the line, the productive workers can return to the line gradually. The group leaders and utility men resume activity during the early stages of the pilot lot. Where production men are brought back on a basis of seniority, they may work on any or all jobs in the line before being specifically assigned to a particular task. This procedure was originally thought impossible. When insisted upon by some unions, it was found to result in more versatile workmen and in a much more flexible working force that can be shifted from job to job.

We have mentioned in Chapter VIII the scheduling of the lines in the early stages for more than they can possibly produce. To reiterate, it is only by being forcibly accelerated in this fashion that the line will reach the desired rate within a reasonable period of time. Also, the line must be forced into production ahead of time and must not wait until everything is ironed out and ready for smooth operation.

## EXECUTIVE READING

"Short Runs Go Straight-line," *Factory Management and Maintenance*, Vol. 97, No. 9, p. 50. Gustav R. Maass, shows how flexible layouts allow a radio-cabinet manufacturer to make use of line production for short runs.

"Made to Order, but Built on the Line," *Factory Management and Maintenance*, Vol. 92, No. 6, p. 258. W. Peaslee describes machines that began by being "ready-to-wear" and ended by being "custom-made."

"The How of a Switch to Mass Production," *Factory Management and Maintenance*, Vol. 96, No. 1, p. 88. Article by R. J. Emmert.

## CHAPTER XVI

## MODIFICATIONS OF LINE PRODUCTION

This study of line production would be incomplete without considering its variations and special applications which, though not strictly line production, are closely related to it. Actually, very few plants are set up entirely on a production-line basis. The majority have some degree of flow but vary in the extent to which the principles of line production have been applied. Thus most production shops adapt the ideas of line production to their own conditions with practical modifications.

**Progressive Machine Groupings.**—One of the earliest attempts to take advantage of the flow principle was the arrangement of job-lot departments or groups of machines into a progressive sequence. The flow was based on the sequence of operations which most of the products followed. Although there was progression of the work from department to department, this arrangement still represented a layout in terms of process or functional groupings.

As soon as a progressive arrangement of functional groups is devoted to only one product, it closely resembles line production. The automotive industry early followed this type of layout as shown in Fig. 6 on page 18. Frequently, such equipment groupings can be connected by a conveyor which passes through them. Functional layouts connected by conveyors in this way are particularly applicable where balancing is difficult because operation times cannot be broken down or because operations of one type must be kept together. The first case may be illustrated by an operating sequence in which one operator can handle work that subsequently requires eight or ten workers to perform their operation. The latter case is found in certain food-processing lines where rows of sorters, peelers, corers, and slicers are grouped along a number of tables, and different produce is handled at different times.

An arrangement such as that in Fig. 108 shows functional groupings of machines in sequence and reserves certain pieces of equipment in each grouping for several specific products of one type. Each product follows a more or less predetermined and reasonably straight-line routing; yet there is considerably greater flexibility than if separate production lines were set up.

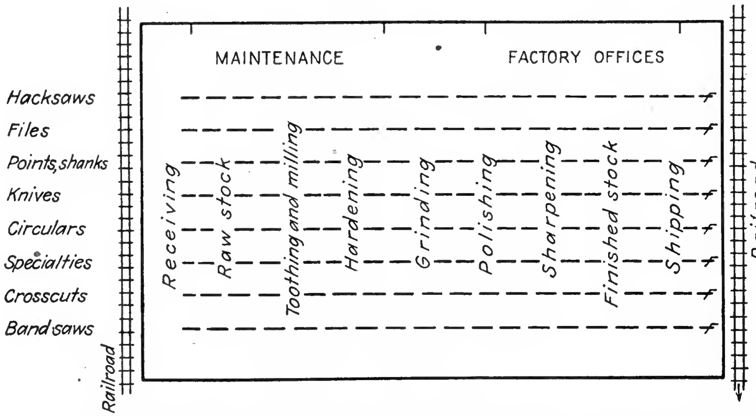



FIG. 108.—Flow through functional departments in a plant manufacturing a variety of saws.

**The Broken, or Extended, Line.**—We have seen examples of lines that turn corners and vary in height. A further modification is the broken line, where, following the completion of a sequence of operations, the line ends, and the material is transported some distance before the line is reestablished elsewhere. When, even in a processing sequence, there is an operation that must be performed in a process-controlled area (such as heat-treating or plating), the line is interrupted and the second series of operations begun in a different department. Some plants have found it easier to control production and yet have considerable flexibility by arranging departments consisting of several short lines. Parts pass through a control area, or stock point, before transport to the subsequent line in the next department.

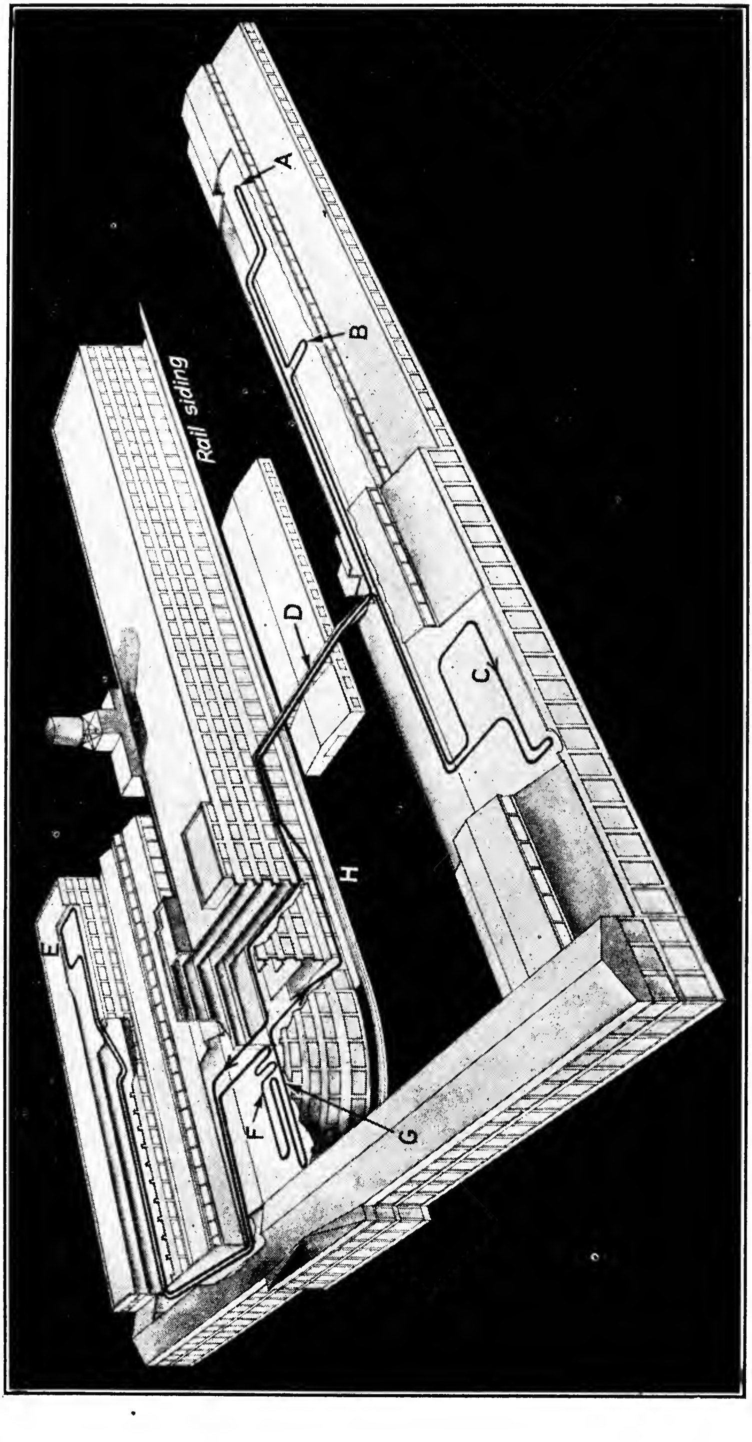



FIG. 109.—Hundreds of ft. of an endless overhead conveyor tie these wheel-making operations together. Figures show the following sequence: *A*, roll rim; *B*, weld; *C*, punch spokeholes; *D*, conveyor overpass; *E*, assemble spokes and inspect; *F*, clean and rustproof; *G*, paint and bake; *H*, ship. (*Courtesy of Jervis B. Webb Company.*)

In a rubber company, a layout was required which would locate the line in two buildings on different floor levels. The line was straight in both sections and connected by a conveyor running between the buildings and floors. When a unit, in moving from one line or machine to another, is put on a conveyor, it can be transported easily several hundred feet or a few inches. Such conveying equipment makes line production possible in many older buildings with limited floor-space areas. Again, it makes possible the use of widely separated work stations, as shown in Fig. 109.

In addition to limitations of space, there are other factors which make it undesirable to fabricate a complete unit on one

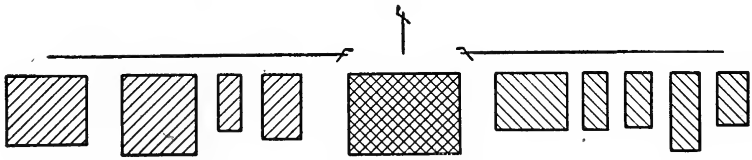


FIG. 110.—Flow over two lines and through a common machine.

continuous line. For example, in aircraft assembly, the fuselage may have to be assembled perpendicular to the line of flow and then turned around before the wings are mounted. In a U-shaped layout, the line may be interrupted to allow switching the parts to the return section of the line. More important, broken lines are often in order as a means of gaining added flexibility in the sequence of the float. A break in the line will allow routing certain units ahead of others which have been held up by delays or defects.

**The Common Machine or the Combination Line.**—In many layouts one piece of equipment may be common to two or three lines. Here the common machine is readily accessible to the products going over the two or more lines. In Fig. 110, one machine performs an operation in two lines simultaneously; the parts are so mounted that the machine can fabricate both parts, one from each line, at the same time. The two lines flow toward each other, and, after passing through the common machine, the parts are trucked to the assembly bank.

Situations may develop where there is a group of common machines. For example, there may be a group of fast machines, such as semiautomatic lathes, which are used on several parts. While the parts are made chiefly on individual lines, fewer high-speed machines will be needed if these operations are done in one area with the machines put together as a common group. These machines may be cycled on

FIG. 111.—Both operators and work move on this line. Each girl carries the complete unit through all operations. (*From American Machinist.*)

specific parts or set up for different parts according to a schedule coordinated with the several lines being fed.

**Functional Layout by Products.**—The dividing of areas laid out by process into smaller integrated areas is similar to the combination line. This is a fairly recent development resulting from mass producers being forced to work on certain lower volume orders. Machines continue to be grouped by type, but there are fewer machines, and each supervisor, instead of being responsible for only one part (as on a line) or one type of machine (as in functional layout), is responsible for a specific number of parts, each of which may pass over several machines in his department. Behind this is the principle that underlies the line-production theory of supervision: it is easier to keep track of a few parts, though they involve different types of operations, than to follow only one process for many different parts. Here the foreman has several parts and several machine types. Small departments

Fig. 112.—Clean-up and inspection stations at the end of a disassembly line. (*Courtesy of Jerpe Commission Company.*)

such as these may be arranged to feed into subsequent fabricating, processing, or assembly operations.

**Moving Workers.**—Another common variation of method is that of moving men through a row of stationary assembly fixtures. By our definition, this is not line production, but it accomplishes the same result where it is impossible or impracticable to move the material. Obviously, in gardening, the earth cannot be brought to the different specialized workers. The plow, harrow, and seeds must go to the soil.

In some cases of line production, this flow of workers can be satisfactorily combined with movement of material on the line. In Fig. 111, the workers are moved, since one operator cannot be kept busy at any one station. Here, however, the work moves with the operator so that we do have line production.

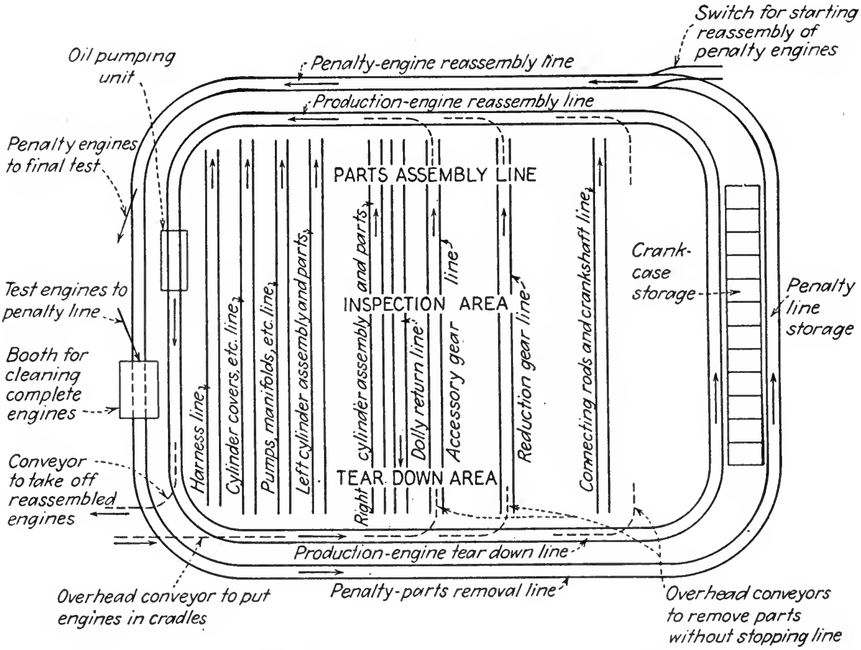



FIG. 113.—After an initial "green" test run, airplane-engine builders make a complete teardown, inspection, and reassembly of each engine. This layout shows how it is accomplished at one plant. Engines from test start down one side of the loop, where they are disassembled. In the middle of the loop the subassemblies and parts are disassembled, cleaned, inspected, and reassembled. Each rack or basket of parts is tagged with the number of the engine so that they will be kept together until replaced into the same engine. Engines which fail are put over the penalty line. (*From Wings.*)

In large assemblies, such as railroad cars, workers may be cycled through several units a day, with the cars on the line being moved along an equivalent number of stations each night.

**Repair Line.**—Inspection operations arranged on a line-production basis have been mentioned. Similarly, repair lines can be set up with the work routed through different stations and with each operator making certain repairs. For example, assemblies which have failed to pass inspection can be sent over such a line for major repair or simply for touch-up. Several organizations have set up repair lines in the field for complete overhaul of equipment and installation of replacement parts.

**Disassembly Line.**—Disassembly, also, can be organized on a line basis. Figure 112 shows a few stations in a chicken-eviscerating line. Again, in the packing of army trucks for overseas shipment, one automotive producer carried on assembly and disassembly simultaneously on parallel lines. As a tested truck was dismantled on one line, the parts were packaged and nested together in a shipping crate which moved alongside the disassembly line. Figure 113 shows an arrangement for disassembly and rebuilding of engines.

The salvage line is another example. Here, if the unit is not satisfactory, it may be transferred to the teardown line. The disassembled parts are reinspected and returned to stock or sent to salvage.

# CHAPTER XVII

## PROBLEMS[1]

### 1. CAFETERIA LINE

*(Elements of Line Production)*

What are the fundamental differences between a cafeteria line and a smoothly operating assembly line in an industrial plant?

How might cafeteria lines be speeded up?

Think up two other everyday, nonmanufacturing examples of line production.

### 2. KILLAM GUN COMPANY

*(Failure of Parts to Assemble)*

Located in a medium-sized town, the Killam Gun Company has for years produced a complete line of sporting arms. With the coming of the defense program, the company began production on barrels and receivers for light military arms. Later, the company was asked to expand its assembly facilities and wood shop and to convert its shotgun departments to handle a large contract for an entirely new rifle.

Under this new plan the Killam Gun Company held a prime contract to deliver to the district ordnance chief 5,000 guns per week after the first 6 weeks of production. Production would start 11 months after the contract was signed. The ordnance office had foreseen that, in order to meet this schedule, many of the parts would have to be subcontracted; he was able to supply the company with a list of manufacturers capable of handling the production of the small parts.

The company took the government specifications together with the government tool and gauge design for this new rifle. Equipment was converted, new and special machinery purchased, and tools and gauges made up. Arrangements were

[1] The names of all companies used in this chapter are fictitious.

made with three subcontractors to produce most of the small gun parts.

When production got under way, the first parts that came through could not be assembled without extensive filing and fitting. Upon completion, this first pilot lot was sent to the government inspection crib in the plant. Here most of the guns were rejected. The same difficulties were experienced with the second lot. At the end of the week, the government inspection group reported to the district ordnance headquarters that the workmanship was inaccurate.

The works manager wanted to know the cause of the trouble. The chief inspector and the inspector supervising subcontract inspection submitted a written report which was passed on to the works manager. It stated that some of the company's best inspectors had been stationed in the subcontractors' plants and that every part produced had been submitted to 100 per cent gauge inspection before the parts were shipped to the Killam plant. Moreover, both inspectors were convinced that the subcontractors had done an excellent job and that the company's own machining and assembly departments had met all gauge requirements, for practically every part had been reinspected and all the gauges themselves checked back to the blueprints for accuracy.

**Problem.**—Wherein lies the probable cause of the difficulty, and how might the company have prevented its occurrence?

### 3. FLASH, INCORPORATED

*(Handling of Material on Production Lines)*

In peacetime, Flash, Incorporated, produces a variety of parts and assemblies for the automotive industry and also makes its own products. The output of the company includes such items as steering-gear assemblies, shock absorbers, gasoline pumps, and candy- and cigarette-vending machines. The concern is located in Toledo and normally employs close to 1,500 hands.

With the war-production program came a great demand for tanks, tank destroyers, and tank-recovery vehicles. When the Ordnance Department found that the production of these vehicles had to be stepped up sharply, the tank manufacturers were forced to look for outside sources of volute suspensions, or bogies. Since Flash, Incorporated, had had years of experience supplying these very manufacturers, it was natural for the company to be approached as a prospective producer of tank components. The concern itself was looking for war work so that, although the plant had never before handled so heavy a product, the job was undertaken. The company became the primary source for three tank manufacturers in the medium-tank program. Production was anticipated to run about 60 suspensions per hour.

The suspensions are, in effect, "knee action" units, six of which bear the weight of the entire vehicle. They are mounted on the side of the tank hull and roll along inside the shoe track, or tread. Some 20 major parts make up the unit exclusive of the attaching parts. The unit itself and some of these individual parts are shown on the accompanying drawing. Although the suspensions stand only waist-high, they weigh nearly 800 lb. Wheel assemblies weigh about 80 lb. each.

In planning how the job was to be done, the production engineers decided to subcontract most of the fabricating work. The small, standard parts could be purchased. In this way the company would, for the most part, merely assemble the units and, of course, control the in-flow of material from outside vendors. The operations to be performed were divided into wheel assembly and final assembly. The floor space set aside for the job occupied the end of a one-story building of reinforced concrete, steel-sash windows, and saw-toothed roof structure.

**Wheel Assembly.**—The wheels themselves were to be welded of steel. This assembly consisted of

| | |
|---|---|
| 1 rim | 1 rubber tire (solid) |
| 1 hub | 1 tubular spacer |
| 1 spider | 2 roller bearings |
| 10 webs | 2 grease cups |

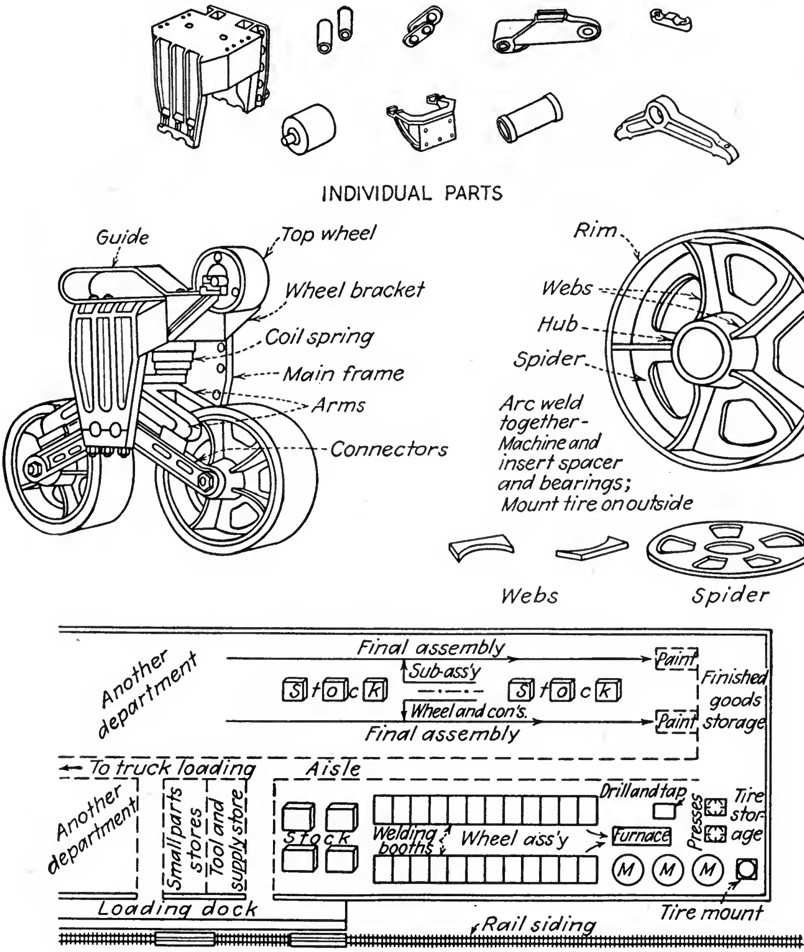
The wheels were to be arc welded on two assembly lines. The spider, hub, and webs were to be added to the rim in that order. Certain amounts of these parts were to be stored inside each booth, there still being ample room for the welder and his bench fixture. This wheel welding could be broken down and handled conveniently in 12 operations. It would require two rows of 12 welding booths each to meet the desired rate of production. The wheels would be moved from booth to booth, progressing toward assembly. After welding, the wheels had to be heat-treated (furnace). The hubs and rims had to be machined (three Bullard Mult-Au-Matics); the tire mounted (hydraulic press), spacer inserted in the hub, and bearings pressed into the hub (two pneumatic presses). The grease-cup holes were then drilled and tapped (special drilling and tapping machine).

**Final Assembly.**—The final line consisted of the following major steps:

Place coil springs (two) in main frame;
Place arms, compress springs, and fasten;
Subassemble wheels and connectors (subassembly line); and assemble to frame;
Turn over;
Assemble top wheel, wheel bracket, and guide;
Inspect;
Paint.

These combined operations and several lesser ones were to be done in two final lines and in each line were to be spread over some 18 working stations of varying space or length. The early operations were to be performed while the unit was upside down. In later operations the suspension was to be upright.

Planning the operations and the layout of the plant involved the problem of handling. Subcontracted parts were to be moved directly from the rail siding (heavier parts) or truck delivery to the lines and stored near the points at which they were to be assembled. Small, standard parts were to be issued weekly to the bins along the lines. Supplies such as welding rod and grease were also issued periodically from the storeroom. Many of these parts could be moved in at night so as not to congest the lines while in operation. Wheel




Volute suspension, wheel and proposed arrangement of the production area of Flash, Incorporated.

assemblies had to be moved to the final lines. Finished suspensions had to be carried to the rail dock for shipment. Most important of all, the work had to be moved from one welding booth to another and from station to station in the actual production of the wheels and final assembly units.

**Problem.**—What materials-handling equipment should be employed throughout this production area?

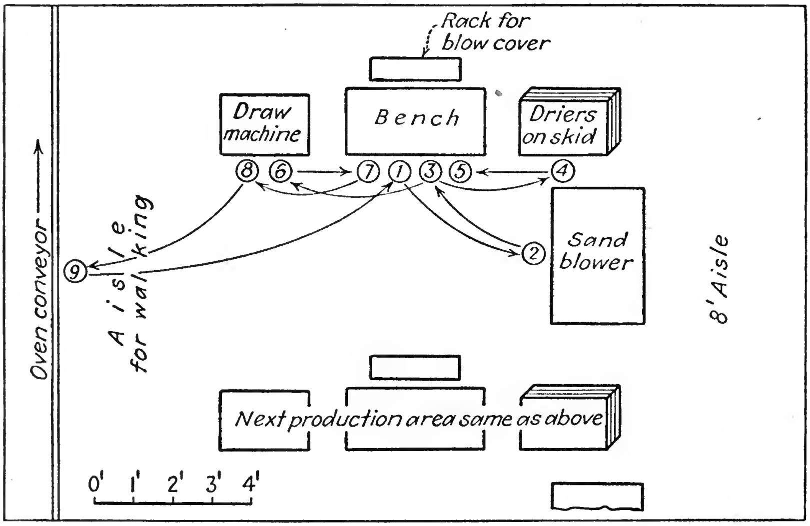
Consider:

1. Movement of raw stock to the point of assembly;
2. Movement of material-in-process on wheel assembly lines;
3. Movement of wheel assemblies to final lines;
4. Movement of material-in-process on final lines;
5. Movement of finished units.

## 4. HEAVYWEIGHT CASTING COMPANY—A

*(Laying Out a Core-molding Area)*

The core-molding department of the Heavyweight Casting Company is facing the problem of handling a scheduled increase in production. The core-blowing section is laid out in a series of 14 similar production areas. These lie next to each other in a row between an oven conveyor, in which the cores are baked, and an 8-ft. aisle and are arranged as shown in the accompanying drawing.




Heavyweight Casting Company *A*. Present layout.

In each of these areas the work pattern is essentially the same. It consists of blowing sand by machine into core boxes, removing the molded sand core from the box, and placing it in an oven. Actually, the sand must be reinforced by wires and must be placed on a drier when not in the core box. The drier is a flat plate with an irregular top which fits the sand core and supports it before it is hardened by baking. A cover through which the sand is blown fits over the core box and forms what will later be the underside of the sand core. Holes in the side of the box allow vent rods and plugs to be inserted for purposes of holding the reinforcing wires.

The present sequence of operations in making the cores is:

(1) Clean box (air jet) at bench;
Place vents (six to twelve) and reinforcing wires (two to six);
Close box (put on blow cover).

○ Carry box to blow machine.

(2) Blow sand into box.

○ Carry box back to bench.

(3) Remove cover;
Clean cover (air jets);
Remove vents.

○ To pile of driers (or plates).

(4) Pick up drier.

○ Carry drier to bench.

(5) Place drier on core box.

○ Take box with core and drier to draw machine.

(6) Invert and draw core (vibration in handle of box).

○ Carry box to bench.

(7) Place core box on bench.

○ To draw machine.

(8) Pick up core on drier.

○ Carry core to conveyor.

(9) Place on conveyor to oven.
Return to bench.

Repeat cycle of operations.

Using this method, the one man in each work area can make about 15 cores per hour. For the new job which the company is taking, production requirements will range upward from 100 per hour. There are 23 different types of cores to be made, so that each core-blowing area will be in use.

At first, there was the feeling that it would be impossible to handle this work in the present production areas. It was realized, however, that the current methods involved excess walking and lifting and resulted in poor utilization of existing machine facilities. The company assigned a methods man to study the job for improvements that would make the 100-per-hour mark possible. The company was willing to triple or quadruple the labor force if the desired production could be attained. As little moving of equipment as possible was, of course, important, particularly in the case of the sand blower, which was supplied with sand from an overhead distributing system.

**Problem.**—How would you rearrange the same production area to handle the new job?

### 5. STORM KING PRODUCTS

(*Layout to Meet Specific Details*)

The Storm King Products Corporation plans to discontinue production within 4 months on the plane it is now assembling at its main plant and to go into production on the new Turnabout. Company officials hope that the plant will be in full production (8 per day in one shift) on the new job 6 months from this time.

The Turnabout is a larger and more complicated plane than the one now being assembled, and the production engineers are wondering how to handle the various assembly and subassembly operations. Typical of the problems faced by the plant layout engineers are arrangements of production lines for final assembly, engine mount assembly, instrument panel assembly, and wing flap assembly.

The present facilities include a large, one-story building. There is one lengthwise bay for the final line fitted with a cab-operated bridge crane. There is also a large production area for subassembly and fabrication. The floor is concrete with wood-block covering.

**Final Assembly.**—The final line will have to be 10 stations long to include the minimum number of operations allowed in the 1 hr. per station. Most of the small installations are to be made on the subassembled units so that on the final line complete major sections are joined. The over-all length of the plane is 50 ft. (40 ft. from center line of wings to tail), and the wingspread is 60 ft. The present final assembly area is 450 ft. long. It is not wide enough for two lines. Layout engineers hope to have 10 ft. of room for moving between ships and still use only this same area for the final line. A powered drag-chain conveyor in the floor with cradle fixtures on wheels is to be used for moving and supporting the plane on the line.

**Engine-mount Assembly.**—Motors (two per ship) are delivered to the plant by rail and transported within the plant on special holding racks by individual lift trucks. Before being joined to the plane they must be set in the mounting and must have attached to them such bulky material as exhaust manifolds, wiring and fuel lines, engine accessories, etc. This work will require 8 hr. per mounting. Engines are to be supported from a special overhead bracket hanging from two parallel monorails. In this way workmen can move around the engine with ease and still work at a convenient height. The engine-mount assembly is to be moved directly to the assembly station on the final line when complete.

**Instrument-panel Assembly.**—Instrument panels (one per ship) are also purchased but require some 12 hr. for checking and attaching of connections in order to save time on the final line. The panels are to be held in bulky fixtures about 6 ft. high and 6 ft. long and supported on wheels. A U-channel in the floor guides the wheels. Operators can work only from one side of the panel. Platforms and seats for workers, portable tool and stock racks, and many overhead-supported power tools are part of the equipment to be used.

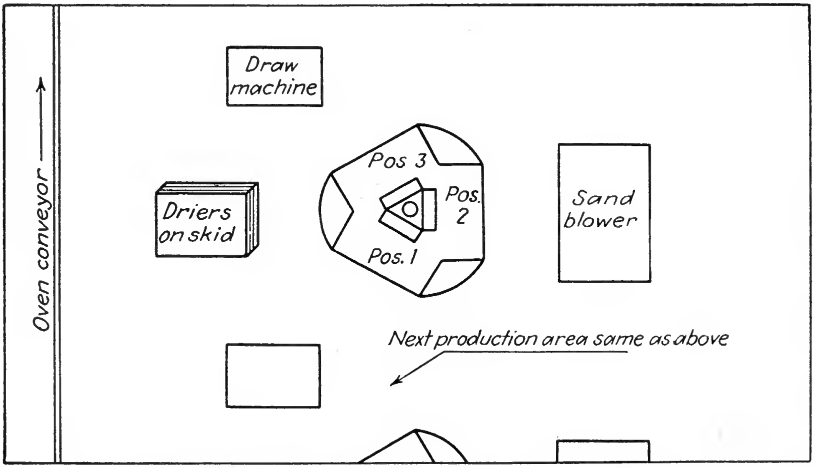
**Wing-flap Assembly.**—The wing flaps are 15 ft. long and are about 32 in. × 12 in. in cross section. These are to be assembled from scratch on portable, bench-type dollies which can be pulled by power along the line lengthwise. Operators work from both sides of the line. Small power tools are used all along the line. Some 22 stations are needed for a complete flap assembly.

**Problem.**—Show by rough sketch the layout of each of the four separate assembly lines, and explain your reasons in each case for the arrangement selected.

## 6. HEAVYWEIGHT CASTING COMPANY—B

*(Balancing Operations)*

In the new arrangement of the core-making department, the series of production areas were laid out as shown in




Heavyweight Casting Company *B*. Arrangement requiring balance.

the accompanying drawing. Operations 1, 3, 5, and 7 (see Heavyweight Casting Company—A) are done on a turntable. Operations 8, 9, and 1 can be done by one man, operations 2 and 3 by man in position 2, and operations 4, 5, 6, and 7 by still a third worker. The table is rotated intermittently by hand. On a certain part, production requirements called for

113 cores per hour. Without the aid of time study, the foreman broke the job up as here shown.

| | Time per Piece in Minutes as Determined Later by Time-study Dept. (Not Including Allowances) | |
|---|---|---|
| Operator No. 1: | | |
| Go to draw machine | 0.07 | |
| Pick up drier and core | 0.02 | |
| Carry drier and core to oven conveyor | 0.05 | |
| Place on oven conveyor | 0.05 | |
| Return to turntable | 0.05 | |
| Finish placing vents and wires | 0.20 | |
| | | 0.44 |
| Operator No. 2: | | |
| Close box | 0.05 | |
| Move box to sand blower | 0.03 | |
| Blow sand | 0.07 | |
| Return box to turntable | 0.03 | |
| Remove cover | 0.03 | |
| Clean cover | 0.05 | |
| | | 0.26 |
| Operator No. 3: | | |
| Remove vents | 0.10 | |
| Go to skids | 0.02 | |
| Pick up drier | 0.04 | |
| Carry drier to turntable | 0.02 | |
| Place drier on core box | 0.02 | |
| Carry drier and box to draw machine | 0.05 | |
| Invert and draw core | 0.05 | |
| Return box and place on turntable | 0.04 | |
| Clean box | 0.05 | |
| Start placing vents | 0.15 | |
| | | 0.54 |

With this arrangement, the workmen could not get out the production needed even without considering the normal time of 15 per cent allowed them for personal needs and fatigue. To improve the job, operator No. 2 automatically began removing the vents in his spare time. When the job was time-studied, it became evident that the work and balancing could still be improved.

**Problem.**—Using the same equipment and layout, rebalance the line of the three operators to get the 113 pieces per hour, giving each worker his 15 per cent allowance over time-study figures. Show the method you use.

## 7. COUP DE GRACE MOWER COMPANY

(*Balance for Increased Machine Utilization*)

Recently the Coup de Grace Mower Company was asked to double production on a certain item (see page 289). At the present time the operations are: bottom, top, and sides milled; four holes drilled and spotfaced; and six holes (three on each side) drilled, tapped, and chamfered to remove burrs raised by the drilling and tapping. The present production is 160 pieces per day, and the new requirements increase this to 320, or double the present output. A slight addendum (probably about 10 per cent) over this is anticipated in the future to meet spare-parts requirements and scrap losses.

The drilling, tapping, spotfacing, and chamfering are now done on a four-spindle gang drilling machine. It takes 21 min. to drill ten holes, tap six, and spotface four, burring and jigging included. This is 2.85 per hour per operator, or 22.8 per shift. $160 \div 22.8 = 7$, therefore, seven operators are required. Since the company operates two shifts and sometimes three, it holds down equipment by running four men one shift and three the next, with one machine either idle or temporarily open for other work on the second shift. This means that four drilling machines and four duplicate box jigs will be required.

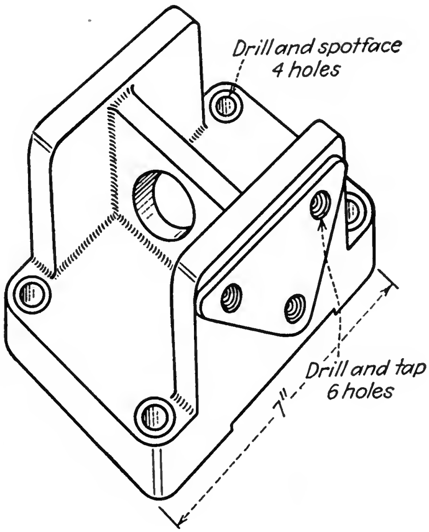
The operator now uses a conventional jig, drilling the four large holes with the jig inverted and spotfacing them with the top side up. He then drills the smaller tap holes in each side, removes the work from the jig, and taps the holes. The burr is removed from the tapped holes by chamfering with the large drill.

The times for these operations (including time for each operator with his work to move from spindle to spindle of the machine) are here given:

| | Number of Minutes |
|---|---|
| 1. Clean and load jig | 3.00 |
| 2. Drill 4 large holes (first spindle) | 4.00 |
| 3. Spotface 4 large holes (second spindle) | 2.50 |
| 4. Drill 6 tap holes, three each side (third spindle) | 4.00 |
| 5. Remove from jig | 0.50 |
| 6. Tap 6 holes (fourth spindle) | 4.80 |
| 7. Burr 6 tapped holes (first spindle) | 1.80 |
| 8. Put piece away and get another | 0.40 |
| | 21.00 |

Each piece receives 100 per cent inspection in the shipping room.

To double production, the company first thought of adding an extra shift of five men and an extra man on each of the first




and second shifts. This would have been a satisfactory arrangement but would have demanded an extra machine of the present type. Delivery was 3 weeks distant on such a standard machine and the increased output was needed within 2 weeks. Moreover, the company was already badly in need of the present four drilling machines for other work, on which the production engineers felt they could be used more effectively.

The company next considered a special machine to drill all the holes at one time (two sides and bottom). The machine would tap both sides at the second station and do the spotfacing and burring at the final station. It would be semiautomatic, with one operator loading and one unloading, and was estimated to cost $15,000, including engineering and manufacturing. This machine would produce 20 pieces per hour, or 320 in 16 hr. Such a machine would hardly pay for itself as it was uncertain how long the job would last. Furthermore, the delivery time on such a special machine was 3 months. Even on the procurement of multiple-spindle drill and tapping heads, delivery was 6 weeks. Also, the required accuracy on the job, as well as other practical limitations, prevented the use of combination tools to drill and spotface or tap and burr simultaneously.

The production engineers then considered changes that could be made in existing equipment already in the shop or any adaptations that could be made from spare machinery that was available.

First of all, they found that, by changing the design of the jig and using a receding bushing head with each drill spindle, all operations could be performed while the piece was in the jig. In this way the large-hole drilling and spotfacing could be done from the top without inverting the piece, though two different tools must still be used. With the tapping and burring performed in the new jig, it was estimated that a 20 per cent saving in time could be made on these two operations. The new jig should also cut 1 min. off the loading and unloading time.

The production engineers found further that there were available five single-spindle, small, but powerful, bench drill presses. These had been used previously in drilling heavy sheet metal, a job which went into larger quantity production and was being punched out on heavy presses. The reversible tapping chuck, on the present No. 4 spindle, could be mounted on any one of the small drills, satisfactorily performing tapping operations at the same speed as at present. Though a tapping machine with lead screw perhaps would be preferable, there was none on hand, and none could be obtained immediately.

The production engineers presented these facts to the chief production engineer, stating that they could meet the increased-production problem and free the present four gang drills for other work. The chief production engineer approved the plan.

**Problem.**—How do the production engineers plan to handle the job? Use sketches and explanation. Any savings in time made through the reduction of walking or the elimination of fatigue are not considered in the engineers' calculations, though, of course, they will try to make such savings.

## 8. BLIMPO BROTHERS

*(Organization of Supervision on Parallel Lines)*

The Blimpo Brothers Company is building large gas-inflated airships. The gondolas for these nonrigid sky cruisers are made on an assembly line of some 12 stations. Each unit is about 50 ft. in length and stands some 18 ft. above the floor conveyor on which it moves intermittently in a straight line.

Supervision on the line is in the hands of two general foremen, each in charge of six stations. Under each of these two general foremen are three supervisors who cover two stations each. Some 12 to 15 employees work in each station.

With an increased demand for these airships, the company found it necessary to install a second assembly line for the gondolas. It was to be laid out in exactly the same way as the first line and to be located in a newly constructed assembly bay parallel to and adjoining the initial line. Because of inadequate storage space along the first line, the company decided to make the new bay extra wide and to store material to be assembled on both lines between the two lines. This meant that the lines would be about 80 ft. apart.

A problem in organization arises in regard to supervision of the new arrangement. If the two foremen merely expand their work, they can cover the same six stations with which they are now familiar but on both lines. On the other hand, it is felt that there are certain advantages in having each general foreman responsible for a complete line.

**Problem.**—What are the advantages of each method of organizing supervision? Might a more satisfactory arrangement of supervision be made?

## 9. STANDARD NUT AND BOLT COMPANY

(*Study of Materials-control System*)

The materials-control system of the Standard Nut and Bolt Company is shown in Fig. 77, Chap. X. The company for many years has produced a variety of nuts, bolts, screws, washers, and other small standard parts. Recently, it has gone into the field of supplying special parts and has left the standard, large-volume runs to other manufacturers. However, it still maintains its business of assembling into paper bags various machine bolts and nuts which are sold as assortments to the general public. These products are purchased in volume from the other manufacturers and assembled at the plant of the Standard Nut and Bolt Company. Models *A*, *B*, and *C* are the company's major assortments in this line.

**Problem.**—1. When a new model is added, what must be done in this control system for the items of material already on the records? . . . for those not on the records?

2. Explain what is meant by the usage-per-unit quantity.

3. Calculate the total parts requirements for Part No. 4062, machine bolt and nut, to cover this production release.

4. What should be the weekly delivery schedule for Part No. 4062? Show calculations.

5. In the Material Follow-up Record, the Order Total opposite the receipts of 4/3, Order No. 375, equals 45,000. How is this obtained? How is the 76,000 in the Accumulated Schedule column obtained?

6. How is actual check made to prevent the occurrence of material shortages?

## 10. ARROW AUTOMOTIVE CORPORATION AND MASTER MOTORS, INC.

*(Comparison of Procurement and Follow-up Policies)*

The Arrow Automotive Corporation is one of the large producers of automobiles and trucks. Centrally located in Detroit, this corporation maintains several plants in that vicinity. The purchasing department for all of these plants is located in the administration building at the company's major plant.

The organization of the purchasing department is headed by the chief purchasing agent. Under him are the assistant purchasing agents who are responsible for securing reliable sources of material for each of the various types of product for which they are responsible. Under these assistants are a number of buyers, each having cognizance over the procurement of a number of specific products. Generally, these products are related to each other, so that one assistant purchasing agent, for example, will have charge of all rubber and related items. The buyers under him might be responsible for such items as tires, fan belts, running boards, and floormats. Still another might be in charge of hard-rubber products, such as steering wheels, storage batteries, etc.

A file is maintained of all possible sources of supply. Although the company tends to do repeat business with its reliable vendors, it solicits competitive bids from all concerns in order to make sure that the prices are in line. In the case of all new vendors, the company not only requests bids but on all important items actually sends out field men to investigate their management and facilities. Records are maintained, of course, of the previous prices paid to the various suppliers, of any quality complaints the company has made, and of the service rendered by each particular vendor.

In general, since the automotive industry has an annual model change, the company likes to place a blanket order with suppliers to cover its entire requirements for the current model. In this way, the company buys ahead of time for the entire model at a specific price, although it does not specifically purchase a certain amount. Actually, at the time each vendor quotes his price, he is guaranteed a minimum quantity which will be bought; but, above this, the supplier is expected to be in a position to furnish the Arrow company with its full needs at the price per piece which has been decided upon. This does not limit the company to a single source of supply.

Master Motors, Inc., with assembly plants scattered throughout the United States, also maintains a central purchasing department in the automotive area. Most of the company-manufactured parts, such as motors, fender stampings, and axles, are shipped from Detroit to these assembly plants. The purchasing group is organized in a way similar to that of the Arrow company, but the buying is never done very far ahead of time. Actually, the buyers can go out ahead and buy up to, but not over, the amount specified in a material authorization. This authorization has been geared to cover the prospective production schedules and is released to the purchasing department by a central production-planning office on the tenth of each month to cover the following 3 months. However, when the buyer covering a certain item finds that he can secure a favorable price, he can submit a request to the management to outstep the authorization. If it is thought that the price is a particularly good bargain, his request will be approved.

In the case of both these companies, there is the problem of scheduling the shipment of material from the various vendors' plants to meet the building schedules. In the Arrow Automotive Corporation, this takes the form of follow-up groups located in the planning, or production-control, departments of its individual plants. It is their duty to contact all vendors after the purchase order or contract has been placed and to deal with these vendors directly, instructing them periodically exactly when deliveries of material are wanted in order to meet production schedules. In these planning departments, there is also a group of shop schedulers who have the responsibility of controlling the material through the various productive departments within each plant, and a materials supervisor who has responsibility over the materials-handling crew for moving and storing the material within the plant. The members of this follow-up group continually check their files of scheduled deliveries and amounts received. This process acts as a protection against delayed deliveries which might hold up production. When such delay occurs or is likely, the follow-up clerk telegraphs or telephones to the supplier in question to speed the delivery. In some cases, expediters are sent out to hurry material out of vendors' factories and on to the company's plant.

In the Master Motors company, this vendor contact is handled entirely by the buyers in the purchasing department. They receive their instructions from the production-planning department each month as to the intended production schedule and notify the suppliers how much they should ship each month, how frequently they should make shipment, and to which plant material should be sent. When material shortages appear imminent at any of the assembly plants, the buyer is notified by this plant, and he contacts the vendor. The traffic department, with its representatives scattered throughout the country, is notified by the buyer when materials already in transit need expediting or rerouting.

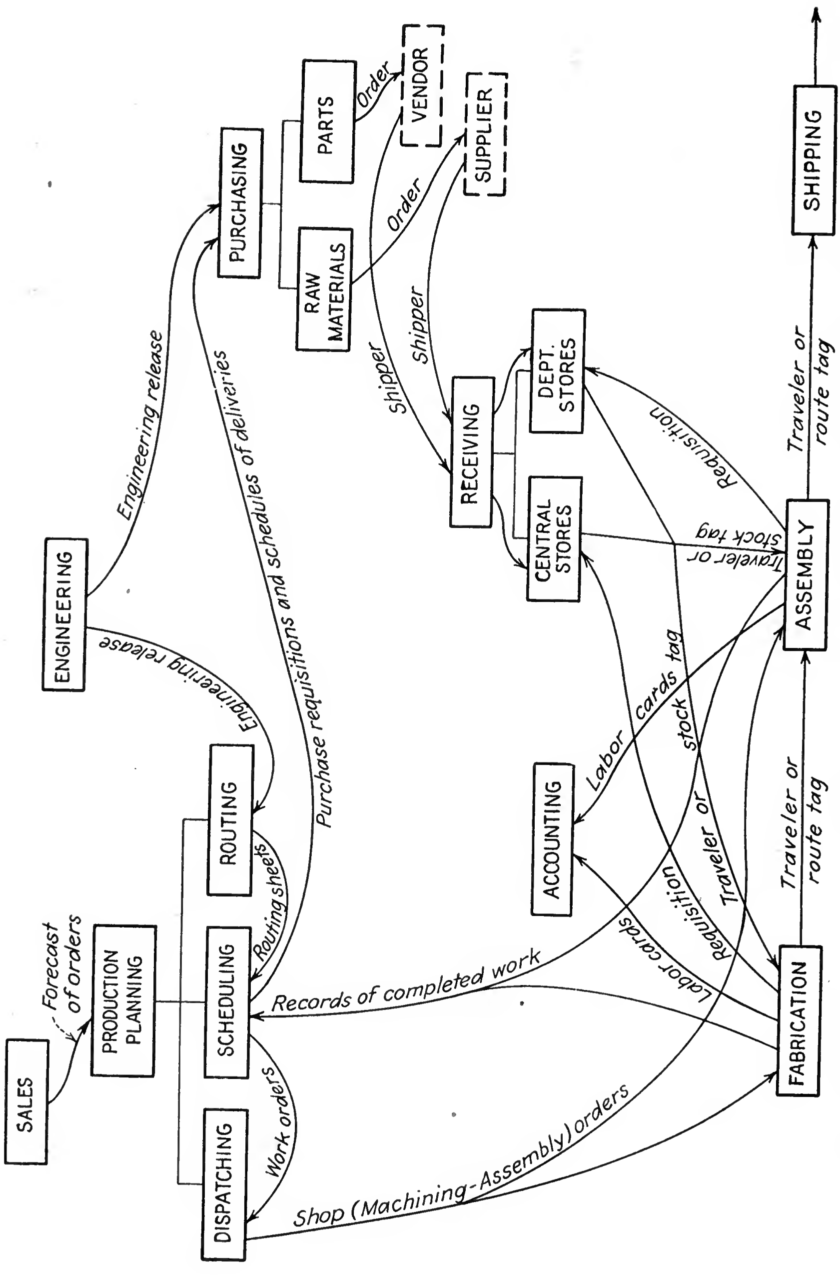
**Problem.**—Comment upon the methods used by these two companies regarding (1) purchasing and (2) controlling material from vendors' factories into their own plants.

### 11. CHARLES RIVER PUMP COMPANY

*(Material and Production Control in Line and Job-lot Layout)*

In considering the conversion to line production, the Charles River Pump Company is wondering what effect this will have upon its system of material control and production control.

The company manufactures three sizes of a standard water pump used for industrial purposes. Its facilities consist of a one-story building which houses the several fabricating areas, an assembly floor, and the various service departments. The




Flow of papers in controlling Charles River Pump Company production. Flow of duplicate copies not shown.

company is planning to set up the production sequence (except for a small miscellaneous machining department) on a line-production basis.

The method of controlling materials and production is shown in the accompanying flow-of-papers diagram. Company officials have been informed that production control is much easier under production-line methods and would like to know what changes could be made in their present system to handle these functions adequately under the new plant arrangement.

**Problem.**—What changes could be made in the system of material control and production control? Sketch a flow-of-papers diagram for the new system and give a brief explanation of it.

## 12. PARADISE GAMES, INC.

*(Control of Maintenance)*

The facilities of Paradise Games Incorporated have been converted from mechanical gaming and vending machinery largely to the manufacture of metal aircraft components. Most of these parts are being made and assembled on production lines. The company has had but little experience with this method of manufacture, and the maintenance foreman is considering a change in his arrangement of maintenance work to serve better the progressive manufacturing operations. The company occupies a two-story building and employs some 500 hands on each of two shifts.

The present handling of routine maintenance and repair work is from a centralized maintenance department divided into mechanical, electrical, and service sections. All sections have men out on the production floors servicing the various departments, although they are not assigned to specific departments or areas. They work out of the central maintenance department, where they keep their tools and their lockers.

The company maintains one full-time employee at a telephone in the maintenance-department office to answer calls from anywhere in the plant regarding maintenance-department work. This call system works as follows: When trouble occurs in the shop the workman or foreman can call the maintenance department. The call is written immediately on a Trouble Order. The employee at the call desk stamps it for time and places it in the partition window, immediately buzzing the assistant foreman of the mechanical, electrical, or service section to pick up the order. It then becomes the assistant foreman's responsibility to see that the necessary repair is made. He may signal on the loud-speaker system to one of the workmen already on the floor to do this work. Possibly the man is on the job already; or if he is tied up on some other important work, he may call the foreman to send out someone from the central maintenance crib. When the job is completed, the maintenance worker reports to his assistant foreman. The record of work done and time is marked on the first copy of the order, which is returned to the call desk. There the job is marked as completed.

The maintenance foreman feels that this arrangement is not entirely satisfactory to handle the servicing and repair of machinery and conveyors.

**Problem.**—What changes would you advocate in the present system? Explain.

### 13. GENERAL NUISANCE TANK ARSENAL

*(Calculation of Man-power Assignment)*

The control of man power for differing levels of production at the General Nuisance Tank Arsenal is largely a matter of ratios. The number of operators needed on each line for the normal rate of production is translated into terms of operators required per piece or per assembled unit. This man-power coefficient is based on time-study figures. From this it is possible to determine the man power that should be assigned to each line as the production schedule varies.

At the General Nuisance Tank Arsenal, there is a reasonably large float, and changes in production schedules are made

GENERAL NUISANCE TANK ARSENAL
Production Schedule No. 11
Department No. 94

Sheet No. 1

| Part number | Name | Operation | Usage per unit | Made through 3-21 | Week ending 3-27 | Week ending 4-3 | Week ending 4-10 | Week ending 4-17 | Week ending 4-24 | Week ending 5-1 |
|---|---|---|---|---|---|---|---|---|---|---|
| D-50974-A | Ring, Turret Race | 10-120 | 1 | 5,664 | 126 | 125 | 120 | 120 | 120 | 100 |
| | Accum. Sched. | | | | 5,790 | 5,915 | 6,035 | 6,155 | 6,275 | 6,375 |
| | Accum. Prod. OK | | | | | | | | | |
| D-46205-8 | Ring, Upper Hatch | 80-185 | 1 | 5,638 | 282 | 183 | 180 | 182 | 189 | 160 |
| | Accum. Sched. | | | | 5,920 | 6,103 | 6,283 | 6,465 | 6,654 | 6,814 |
| | Accum. Prod. OK | | | | | | | | | |

gradually. For this reason it is possible to determine the line population but once each month.

**Problem.**—From the accompanying production schedule calculate the daily man power that should be assigned to the turret-race ring line for the month of April. The man-power coefficient (operators allowed each day per piece produced) is 1.27 as determined by the standards department. The plant is working 6 days per week. What would be the man power assigned for the week of April 3 if weekly calculations were made?

## 14. ST. CLOUD WORKS

*(Job Classification and Special Machinery)*

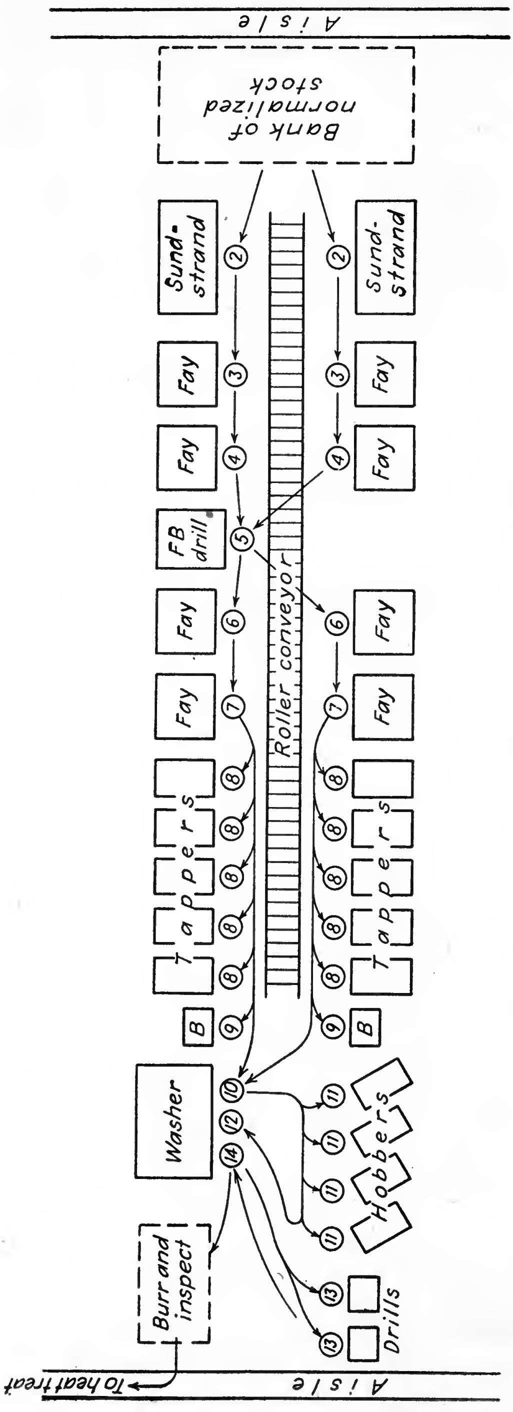
Although a valuable aid in transferring, training, and promoting, job classification is a source of constant concern in the fabrication lines of the St. Cloud Works. All operations in the plant are grouped under a system of job classification. Class 14 includes milling-machine operators, for example. This is based on job-analysis studies whenever possible and is the basis for wage rates. However, improvements are made so rapidly and so often, and so many kinds of special machines are used, that it is difficult to set up an all-inclusive classification that will measure the relative worth of work done on the many hybrid machines. Moreover, on all new operations which do not fall into some group of the existing classification, the foreman on the particular line determines the approximate class and therefore the wage rate.

One example is illustrative of the difficulties encountered. A series of gear-cutting operations is set up to produce so many gears per hour and includes:

| Operation | Machine | Classification | Rate per hour |
|---|---|---|---|
| 1. Hog out | Pratt & Whitney | 14 | $1.10 |
| 2. Shape teeth | Fellows shaper | 22 | 1.20 |
| 3. Round teeth | Company-made rounder | 19 | 0.90 |

Examining these operations, the production engineer and the foreman on the job devise an entirely new combination machine which is almost fully automatic. When they put the new machine in the line, they do not want it to fail; for it would be a reflection on them, and a considerable sum may already have been spent on it. Therefore, at the start, the $1.20-per-hour man is put on the job because he has presumably more skill, although undoubtedly the job could be done by the $0.90-per-hour man if more time were taken to train him. As a result, the job gets the reputation and the operator gets the classification which goes along with the $1.20-per-hour job. When production gets under way on this job, the operation is so easy that the men on near-by jobs complain that they should be getting more money to correspond with the high rate of the simple new job. Situations like this make not only for such uneconomic use of man power that the work is not produced at a reasonable price but also for friction among the working force.

**Problem.**—What can be done about this situation?




Proposed layout of drive-shaft line of Molehill Excavators, Inc.

## 15. MOLEHILL EXCAVATORS, INC.

(*Change in Layout*)

The medium bulldozer built by the Molehill Excavators, Inc., is used in a variety of construction and earth-moving work. Its main power drive runs through two identical shafts. The company is producing these in its present gear department at the rate of 26 per day. Plans for a new layout to handle the part on line production have recently been made.

The shaft is 2½ ft. long. One end is flanged, while the other end of the shank is splined. The rough forging weighs about 35 lb. Operations are shown on page 303. The company planned to make the part on a line consisting of two rows of machinery. A dead roller conveyor at waist height in the middle of the line was to hold the float of parts between operations. These would rest in special wooden boxes. Small, floor-operated bridge cranes would be used in lifting the work in and out of machines. Each machine was set up to perform only its one operation. The proposed layout is shown in the accompanying drawing.

When the new Sundstrands and Fay automatics arrived, the time-study engineers found that one worker could operate two of these machines without any decrease in production so long as both machines were performing the same operation. For example, one operator could handle both Sundstrands in milling the small ends. With this new feature in mind, the layout engineer plans to alter his proposed layout and still use the same handling equipment (roller conveyor, boxes, and crane hoists).

**Problem.**—How can the proposed layout be changed to allow more effective labor usage? Use sketch and explanation.

BULLDOZER DRIVE SHAFT—OPERATIONS SHEET

| Operation | Machine | Machines required |
|---|---|---|
| Inspect forgings and straighten if necessary | | |
| 1. Normalize (heat treat department).... | Normalizing furnace | 1 |
| 2. Mill small end to length and center both ends. | Sundstrand combination milling and centering machine | 2 |
| 3. Rough turn and face flange.......... | Fay automatic lathe | 2 |
| 4. Finish turn and face flange.......... | Fay automatic lathe | 2 |
| 5. Drill ream and counterbore (6) holes in flange.......................... | Foote-Burt drill press | 1 |
| 6. Rough turn and face shank complete.. | Fay automatic lathe | 2 |
| 7. Finish turn and face shank complete.. | Fay automatic lathe | 2 |
| 8. Tap (6) holes in flange.............. | Brakewell tapper | 10 |
| 9. Stamp piece mark.................. | Bench | 2 |
| 10. Wash............................ | Detrex washer | 1 |
| Inspect........................... | | |
| 11. Hob (12) splines.................... | 140 Cleveland hobber | 4 |
| 12. Wash............................ | Detrex washer | 1 |
| 13. Drill and countersink (2) holes........ | No. 2 L and G drill press | 2 |
| 14. Wash............................ | Detrex washer | 1 |
| 15. Burr............................ | Bench | 1 |
| Inspect........................... | | |
| Heat-treat and grind............... | | |

## 16. HOTSEAT FURNITURE COMPANY

*(Fluctuations in Production Schedules)*

The Hotseat Furniture Company is assembling wooden office desks on a production line. In view of crowded warehouse space caused by the bulkiness of the completed unit and the irregular ordering by distributors, the company is faced with the problem of frequent variations in its production schedule.

The production line is straight. The work moves along at a convenient working level on a continuously moving powered conveyor, the assemblies themselves being mounted bottom side up on wooden platform fixtures which are pushed by dogs protruding from the conveyor. Small pieces of equipment and powered hand tools used in putting the assemblies together are located under the conveyor or suspended on overhead balancers at the proper work stations. Other hand tools are placed on each workman's bench in his station. Racks for small stock are placed parallel to the line behind the operators. Two men normally work as a pair in each station, one on either side of the line. The larger parts are fed to the final line by gravity roller conveyors or are held on skid platforms at the point of assembly.

**Problem.**—Assume that production is to be reduced to one-quarter of normal, with further fluctuations in prospect. What changes might be made to handle such varying rates of production?

## 17. GARDEN TRUCK COMPANY

(*Changes in Machine and Operator Assignment*)

At the present time the Garden Truck Company is concerned about more efficient operation of its axle-housing department. There are three lines in this department, on which four different housings are produced.

The company is making trucks—the 2-ton 6 × 6, 2-ton 4 × 4, and 1½-ton. The latter two are four-wheel trucks, while the term "6 × 6" indicates that the first has six wheels with a six-wheel drive. The front-wheel housing is the same for all three models and is purchased from an outside source. The housings which are being produced are as follows:

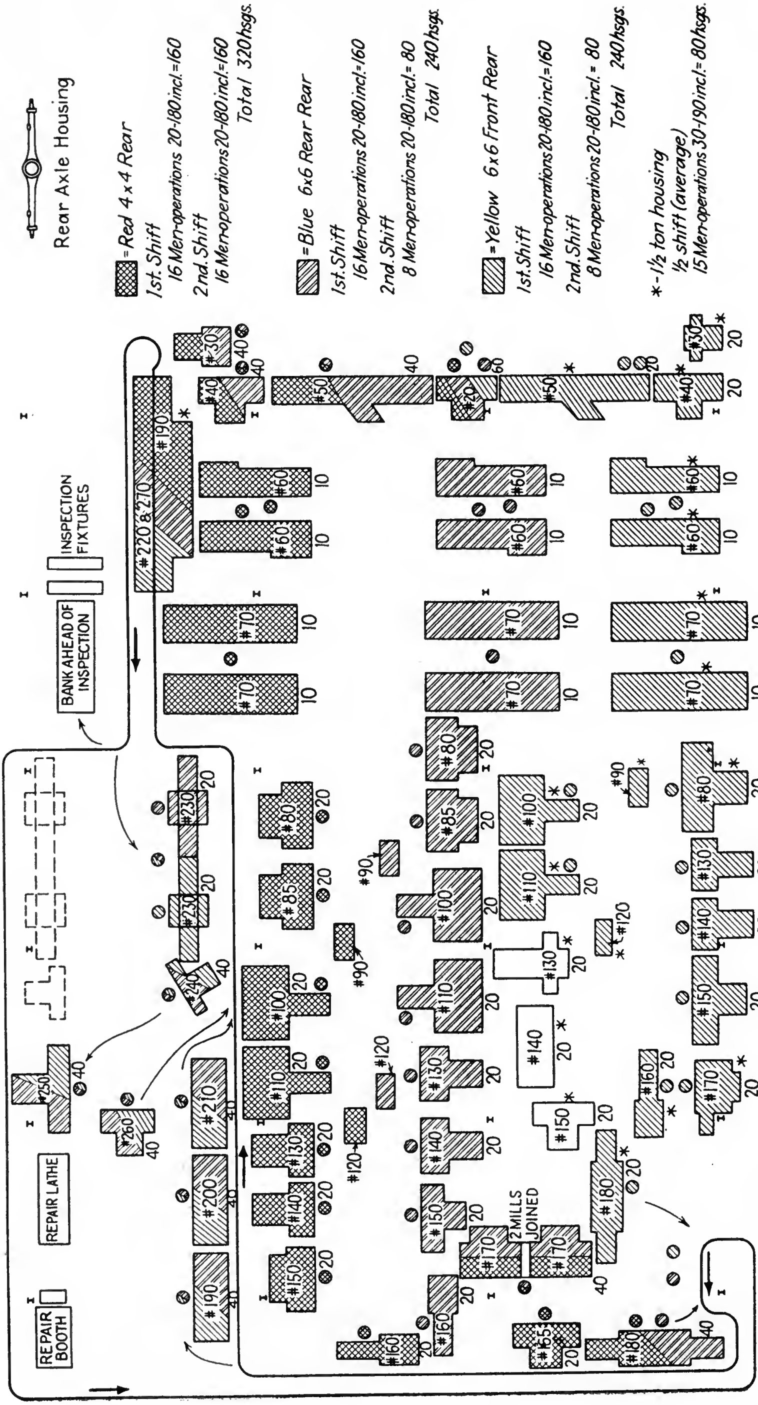
| Line | Housing | Daily rate of production to meet requirements | Operation at 20 pieces per hour, to meet requirements |
|---|---|---|---|
| Red......... | 2-ton 4 × 4 rear | 300 | 2 shifts |
| Blue......... | 2-ton 6 × 6 rear rear | 240 | 1½ shifts |
| Yellow....... | 2-ton 6 × 6 front rear | 240 | 1½ shifts |
| * | 1½-ton rear | 80 | ½ shift (average) |

The accompanying diagram shows the layout of the department. Rail racks on which the housings are rolled from operation to operation are not shown. These are placed in the vacant space between machines so that the department is actually very compact. The float between operations is held on these racks. Likewise, the overhead monorails and hoists are not indicated, though the endless, continuously moving monorail is shown. This conveyor has a special hanger on which the housings can ride in an "up-on-end" position.

In the diagram the small circles represent operators, while the shading indicates the particular housing on which the various machines and operators work. The dotted lines show machines not used by this department or not in use at the present time. The operation number is indicated on each machine, while the production per hour is shown under each machine.

The 1½-ton housing is not assigned to any one complete line. Rather, it is run sporadically over certain machines, several of which are used only for this housing but the majority of which are changed over from the 2-ton 6 × 6 front rear (yellow). The machines used on the 1½-ton housing are indicated by an asterisk(*). This 1½-ton housing may also be put over the 6 × 6 rear rear (blue) line by the same changeover of the fixtures and tools as on the yellow line. The red line is never broken into because there is too much difference in the work. Getting the tools from the crib and resetting the fixtures for this changeover to the 1½-ton job require one shift.

The plant operates two 8-hr. shifts on the three lines 6 days per week. The 4 × 4 (red) line makes 160 housings each




Present arrangement of the Garden Truck Company.

List of Operations, 2-ton 4 × 4 Rear (Red)

| | | |
|---|---|---|
| 10. | Inspect | |
| 20. | Mill gear clearance | Baker drill press |
| 30. | Drill and tap hole in banjo | Cincinnati drill press |
| 40. | Straighten | Dennison hydraulic press |
| 50. | Face ends to length | Barnes two-way drill press |
| 60. | Rough turn, both ends | Sundstrand lathe |
| 70. | Finish turn, both ends | Fay automatic lathe |
| 80. | Face banjo, one side | Baker drill press |
| 85. | Face banjo, other side | Baker drill press |
| 90. | Assemble balance weights | Bench |
| 100. | Rough grind, both sides | Cincinnati centerless grinder |
| 110. | Finish grind, both sides | Cincinnati centerless grinder |
| 120. | Remove balance weights | Bench |
| 130. | Drill and tap (2) 3/8–16 holes | Hammond radial drill press |
| 140. | Drill and tap (2) 3/8–16 holes and (1) 7/16-in. hole | Hammond radial drill press |
| 150. | Drill and chamfer (12) banjo holes, both sides | Baker drill press |
| 160. | Cut threads, both ends | Landis threader |
| 165. | Tap (12) banjo holes, both sides | Baker drill press |
| 170. | Mill keyways, both ends | Cincinnati plain mill |
| 180. | Drill flange holes, both ends | Special two-way drill press |
| 190. | Wash | Washing machine |
| 200. | Inspect | Inspection fixtures, gauges |

List of Operations, 2-ton 6 × 6 Front Rear (Yellow) and Rear Rear (Blue)

| | | |
|---|---|---|
| 10. | Inspect | |
| 20. | Mill gear clearance | Baker drill press |
| 30. | Drill and tap hole in banjo | Cincinnati drill press |
| 40. | Straighten | Dennison hydraulic press |
| 50. | Face ends to length | Barnes two-way drill press |
| 60. | Rough turn, both ends | Sundstrand lathe |
| 70. | Finish turn, both ends | Fay automatic lathe |
| 80. | Face banjo, both sides (yellow) | HO-30 Baker drill press |
| | Face banjo, one side (blue) | Baker drill press |
| 85. | Face banjo, other side (blue) | Baker drill press |
| 90. | Assemble balance weights | Bench |
| 100. | Rough grind, both ends | Cincinnati centerless grinder |
| 110. | Finish grind, both ends | Cincinnati centerless grinder |
| 120. | Remove balance weights | Bench |
| 130. | Drill and tap (2) 3/8–16 holes | Hammond radial drill press |
| 140. | Drill and tap (2) 3/8–16 holes and (1) 7/16-in. hole | Hammond radial drill press |
| 150. | Drill and chamfer (12) banjo holes, one side | Baker drill press |
| 160. | Cut threads, both ends | Landis threader |
| 170. | Mill keyway, both ends | Cincinnati plain mill |
| 180. | Drill flange holes, both ends | Special two-way drill press |
| 190. | Drill, spotface, and taper ream bracket, left hand | Expert two-way |
| 200. | Drill, spotface, and taper ream bracket, center | Expert two-way |

| | | |
|---|---|---|
| 210. | Drill, spotface, and taper ream bracket, right hand | Expert two-way |
| 220. | Wash | Washing machine |
| 230. | Weld cover | Cover welder |
| 240. | Drill and tap drain hole in cover | Cincinnati drill press |
| 250. | Tap (12) banjo holes, one side | Baker drill press |
| 260. | Straighten | Flexible power press |
| 270. | Wash | Washing machine |
| 280. | Inspect | Inspection fixtures, gauges |

List of Operations, 1½-ton Housing(*)

| | | |
|---|---|---|
| 10. | Inspect | |
| 30. | Drill and tap hole in banjo | Cincinnati drill press |
| 40. | Straighten | Dennison hydraulic press |
| 50. | Face ends to length | Barnes two-way drill press |
| 60. | Rough turn, both ends | Sundstrand lathe |
| 70. | Finish turn, both ends | Fay automatic lathe |
| 80. | Face banjo, both sides | HO-30 Baker drill press |
| 90. | Assemble balance weights | Bench |
| 100. | Rough grind, both ends | Cincinnati centerless grinder |
| 110. | Finish grind, both ends | Cincinnati centerless grinder |
| 120. | Remove balance weights | Bench |
| 130. | Drill banjo holes both sides and (2) clip holes | Greenlee drill press |
| 140. | Tap banjo holes both sides and (2) clip holes | Greenlee tapper |
| 150. | Mill gear clearance | Baker drill press |
| 160. | Cut threads | Landis threader |
| 170. | Mill keyway, both ends | Cincinnati plain mill |
| 180. | Drill flange holes, both ends | Special two-way drill press |
| 190. | Wash | Washing machine |
| 200. | Inspect | Inspection fixtures, gauges |

shift and can thus get 320 per day (20 more than required). On the front rear (yellow) and rear rear (blue), the second shift alternates between the two lines each evening. This results in 160 housings each morning and 160 every other evening, or the equivalent of 240 per day. The 1½-ton (*) weekly requirements are run out at one time—480 housings, 24 hr. at 20 per hour, or an average of one-half shift per day.

With the present routing and scheduling of the work, the department is not producing the number desired in the over-all time allowed by the time-study department. This condition may be due to a number of reasons. One is the frequent breakdown of the Sundstrands (Operation 60). These are not really strong enough for the work they are doing, and there is no stand-by equipment to afford protection, so that an entire line is often held up because of machine failure. Actually, the rough facing could be done better on the Fays if they were available. Likewise, there is little protection against the absence of workmen from the department. The transfer of a workman from the next department is usually necessary, resulting in possible damage to work and machinery.

During the changeover for the 1½-ton job and the change back to the yellow setup, there is a great deal of idle machine time when work is not being produced. The operators are also idle, though they do help the setup men. Thus every week the front rear (yellow) line is interrupted to get out a week's run of 1½-ton housings. This uneven flow requires the building up of banks and consequently extra storage space. Moreover, to meet production schedules, it is necessary periodically to move men over from the red line or operate the yellow (or *) line a third shift.

The plant manager is not satisfied with the present arrangement (which has developed from previous models) and has asked the industrial engineers to see what improvements can be made. He does not feel that any machinery should be moved because of possible changes in the scheduled requirements or modifications in design. No new machinery is available. It is even hoped that some machinery may be freed for use by other departments.

The industrial engineers know that, since both the 6 × 6 housings (blue and yellow) are very similar, many of the operations can be performed for both these housings on the machines already in either of these lines without changing the setup. This is being done at present on Operations 190, 200, 210, 240, 250, and 260. The fixtures which are used on most of these machines are of a universal nature because of anticipated changes in design at the time of setting up the lines. Most of the equipment is working at capacity so that if the machine loading is lessened, the man power may accordingly be reassigned. The operators assigned to the present arrangement do their own handling, so that the circles on the chart do not show the exact location of the working position.

Since adjacent departments are operating 24 hr., there is no objection to using three shifts if necessary. The number of workmen on the line can be changed if this will help in efficient operation of the department.

**Problem.**—Without moving any equipment, indicate your assignment of machinery and men to the four axle housings for the best operating conditions. A rough tracing or facsimile of the department, with machines and operators colored in, may show this most clearly. Explain briefly how this arrangement meets the required production.

## 18. PRIMUS INDICATOR COMPANY

*(Variations in Line Production)*

The Primus Indicator Company is in the process of converting its facilities to line production for the manufacture of one of its major products. The production engineers recognize that, because of differences in machine capacity, much of their equipment will not be fully utilized in the new arrangement. They are, therefore, experimenting with modifications of line production by which they might group several parts and arrange the layout so that one machine can perform more than just one operation. They are particularly interested in the economical use of expensive, high-speed machinery.

The chief product of the company is a gyroscopic instrument which is made up of a large number of small parts. These parts are handled in lots on wooden trays or tote pans and are carried by the workmen themselves from operation to operation. The lot sizes are in multiples of 10 up to 50 pieces and in multiples of 50 from there on.

The production engineers believe that one grouping of parts might consist of the following:

A Case cover
B Rotor
C Support
D Wheel
E Synchronizer

Operations List and Machine Assignment

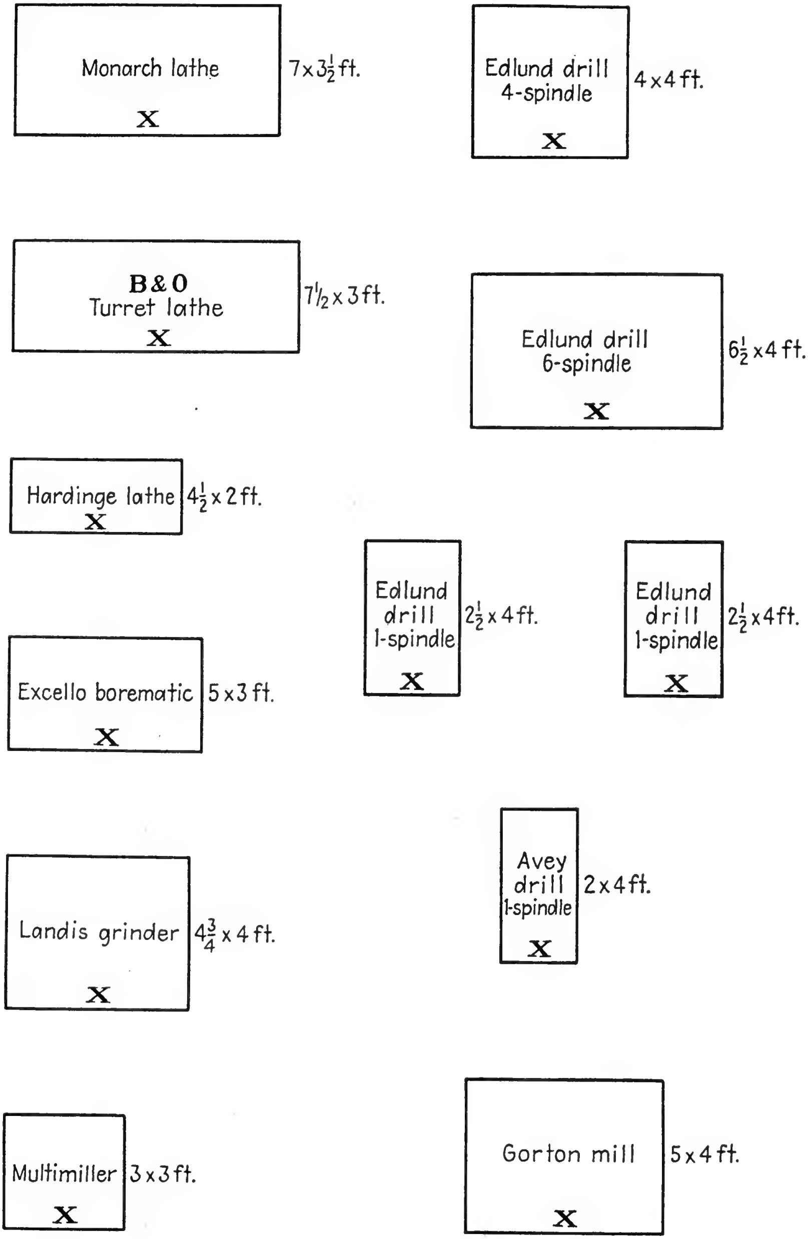
| Operation | Machine | Pieces per hour per machine | Number of machines required |
|---|---|---|---|
| A—Case Cover: | | | |
| 1. Drill 15 holes | Avey drill | 62.0 | 0.24 |
| 2. Finish face hub, chamfer, undercut | Monarch lathe 12 in. | 20.0 | 0.75 |
| 3. Finish turn diameter and face | Monarch lathe 12 in. | 32.5 | 0.46 |
| 4. Form recess | Monarch lathe 12 in. | 67.9 | 0.22 |
| 5. Face 2-in. and $2\frac{1}{4}$-in. bosses | Monarch lathe 12 in. | 29.3 | 0.52 |
| 6. Bore 0.6350 and 0.7800 diameter | Excello Borematic | 138.0 | 0.10 |
| Move to next department, anodize, further machining, etc. | | | |
| B—Rotor: | | | |
| 1. Form 0.885 diameter, chamfer $\frac{1}{16}$ radius, turn $\frac{5}{16}$ access | B & O turret lathe | 33.1 | 0.46 |
| 2. Finish bore 0.3658 to size with parts No. 7682, No. 1385, No. 1239 | Excello Borematic | 138.0 | 0.10 |
| 3. Bore beads and straddle face | Monarch lathe 12 in. | 19.4 | 0.78 |
| 4. Finish grind outside diameter | Landis grinder | 89.8 | 0.16 |
| 5. Scrape and sand inside | Bench | | |
| Inspect | | | |
| C—Support: | | | |
| 1. Turn 0.760, face shoulder undercut, face end | Hardinge lathe | 24.0 | 0.62 |
| 2. Spot, drill, bore, and ream, (2) 0.128 | Edlund 6-spindle drill | 15.6 | 0.96 |
| 3. Spot and drill (2) No. 29, tap (2) 0.148 holes $\frac{11}{32}$ dp, tap (2) 0.148 holes $\frac{7}{16}$ dp, countersink (2) 85-deg. × $\frac{13}{64}$ | Edlund 6-spindle drill | 15.6 | 0.96 |
| 4. Bore 0.385 | Excello Borematic | 138.0 | 0.10 |
| 5. Burr | Bench | | |
| Move to next department, degrease, inspect | | | |
| D—Wheel: | | | |
| 1. Form $\frac{7}{16}$ recess | Monarch lathe 12 in. | 55.2 | 0.27 |
| 2. Finish bore 0.3350 | Excello Borematic | 138.0 | 0.10 |
| 3. Face 2 sides to 0.957 | Monarch lathe 12 in. | 30.3 | 0.50 |
| 4. Mill buckets | Multi miller | 14.4 | 1.05 |
| 5. Finish grind outside diameter | Landis grinder | 6.13 | 0.24 |
| 6. Smooth grind | Landis grinder | 82.3 | 0.18 |
| 7. Burr | Bench | | |
| Move to next department, degrease, burr, inspect | | | |
| E—Synchronizer: | | | |
| 1. Turn 3.348 diameter, face flange 0.109, face shoulder 0.098, face pads 0.333, break edges, burr, gauge | Monarch lathe 12 in. | 23.4 | 0.64 |

OPERATIONS LIST AND MACHINE ASSIGNMENT.—(*Continued*)

| Operation | Machine | Pieces per hour per machine | Number of machines required |
|---|---|---|---|
| E—Synchronizer—(*Continued*) | | | |
| 2. Bore 3.520, form 60-deg. angle, gauge... | Monarch lathe 12 in. | 46.3 | 0.33 |
| 3. Gauge and straighten................ | Bench | | |
| 4. Mill one side to ¾ radius.............. | 8½ Gorton mill | 54.0 | 0.28 |
| 5. Mill other side to 0.065 diameter....... | 8½ Gorton mill | 54.0 | 0.28 |
| 6. Gauge and straighten................. | Bench | | |
| 7. Spot, drill, and ream (1) 0.1845, spot, drill, and ream (1) 0.125, spot, drill, and ream (1) 0.0681........................ | Edlund 1-spindle drill | 22.6 | 0.67 |
| 8. Drill (7) holes, drill (4) 7⁄32 holes........ | Edlund 2-spindle drill multi-head | 31.2 | 0.49 |
| 9. Face (1) ⅛ hole, counterbore and countersink (1) 9⁄32 hole............... | Edlund 4-spindle drill | 71.0 | 0.21 |
| 10. Counterbore (1) 0.1845 hole, countersink (1) 0.0681 hole, countersink (6) ⅛ holes, drill (6) 0.0469 holes.................. | Edlund 4-spindle drill | 27.8 | 0.55 |
| Move to next department, degrease, anodize, and paint. | | | |

Each day 250 units are desired. With a 35 per cent scrap allowance because of the delicate work, the production rate must be 337 per day. The company is working three shifts in the machining departments, or the equivalent of 22½ production-hours per day. The operations, machine capacities (including work handling and operator allowances), and machines required to meet production are shown on the accompanying operations list. No changeover or setup time has been allowed in these figures. If parts are being cycled on a 2-day basis (2 days' requirements run off with each setup), a setup time of 10 per cent of the operating time should be allowed. Also shown are templates (⅕ in. to 1 ft.) of these machines. The building itself is 216 ft. long and 96 ft. wide, with supporting columns 24 ft. apart in both directions. There is a 10-ft. aisle running the length of the plant at one side of the center columns.

**Problem.**—Plan the arrangement of equipment to handle the production of these five parts with best utilization of the




TEMPLATES OF MACHINES

Allow 1 ft. spacing for overhang around all sides of each machine.
X indicates the front of the machine facing the operator.
Scale—1/5 in. to 1 ft.

machines specified. Sketch a section of the plant on standard graph paper (five squares per inch) letting each square equal 1 sq. ft. of floor space. Show the actual location of the machines and indicate the approximate path each part follows (preferably by colored lines). Show all worksheets and explain briefly what you have done.

# INDEX

6-21-45