FACTORY PLANNING GUIDE

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by

LLOYD G. FOSTER

Bachelor of Science

Oklahoma Agricultural and Mechanical College

Stillwater, Oklahoma

1943

and

GEORGE B. TIMS, JR.

Bachelor of Science

Oklahoma Agricultural and Mechanical College

Stillwater, Oklahoma

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APPROVED BY:

H. B. Thuesen
Chairman, Thesis Committee

M. R. Lohmann
Member of Thesis Committee

H. B. Thuesen
Head of School

D. C. McIntosh
Dean of the Graduate School

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CHAPTER I

INTRODUCTION

Every student must know what is to be accomplished before he starts to solve a problem. Instructors use different methods in teaching students how to solve problems. In some courses the student is presented with a step-by-step, sharply defined, and organized procedure to follow in working out the solution of a problem. Other instructors present only general directions and give guidance while the student works out the details, develops the procedure, and solves the problem. With the latter method of instruction in view, the Factory Planning course was added to the Industrial Engineering curriculum to train the student to develop the ability to organize subject matter and to encourage his original planning and thinking.

In the Factory Planning course the effort of the student is directed to the solution of one large problem. Briefly, the problem is to plan an industry for producing a prescribed product at a suitable rate. To satisfactorily accomplish this, the student is required to recall and use subject matter learned in related courses, as well as to search out new information and combine the knowledge gained from these sources into practical design.

A thorough description of this course can best be obtained by summarizing the various steps necessary in its solution. These are:

1. A market survey is conducted by the student to determine the sales potential of the product.

2. A product analysis is made to determine which parts of the product are to be purchased and which are to be manufactured in the plant. This analysis makes it possible to prepare the bill of materials, to prepare an operation sheet for each part manufactured, and to construct the process charts.

3. The method of assembly is described. This is accomplished

by operation sheets showing the sequence of operations and the time and equipment required to complete each assembly operation.

4. From the information accumulated in the preceding steps, the number and type of each processing machine may be determined. Such factors as amount of and cost of lost time due to breakdown, cost of operation and maintenance, safety features, and initial investment must be given consideration in arriving at the most economical machine requirements.

5. At this point a flow chart is drawn indicating the sequence of manufacturing and assembly operations as the product progresses from the raw material to the finished product stage.

6. The necessary management and supervisory personnel parallel the determination of the type of organization to be used. The organization chart must include all personnel necessary to perform all activities incident to the manufacture of the product; such as, employment, requisition of equipment, accounting and cost records, receiving and issuing stores, advertising, maintenance, shipping and other activities.

7. The necessary floor space for each piece of equipment is calculated, and a tentative layout for all manufacturing and conveying equipment is determined. Space requirements must also be calculated for administrative offices, service departments, storage, shipping departments, and others.

8. The type of building to be used and a definite plant site are selected. The general, and possibly the specific locale, may be determined as a result of the market survey. Consideration must be given to such factors as transportation facilities, source of raw material, nearness to market, availability of labor and utilities. The price of labor, rates of the utilities, initial land expense, taxes, and other factors that affect cost must also be considered.

9. Layout drawings of the grounds, manufacturing or production department and building are made.

10. A suitable heating and ventilation method as well as a satisfactory illumination system is designed.

11. An investigation, based on current prices, is conducted to obtain the estimated cost of the entire plant. For clarification purposes this is presented in the form of a balance sheet. A profit and loss statement is set up for one particular period of operation.

12. A report is prepared for the purpose of summarizing the work accomplished during the course. The data used, sources of information, assumptions made and conclusions

drawn are co-ordinated with suitable explanations to give the reader a clear, well-defined view of the proposed industry.

Since 1928, the year the Factory Planning course was introduced by Professor H. G. Thuesen, there has been a need for a written guide that would act as a foundation upon which the student could build. A continuous search of the published material in the field of Industrial Engineering has failed to produce the desired aid. Two years ago the writers started gathering material and composing what they hope will satisfy the need for a written guide.

With the view of keeping the same method of instruction and course content, the writers have attempted to formulate this thesis so that it will aid the student without subtracting from the "creative engineering" demanded of him.

CHAPTER II

PRODUCT ANALYSIS

Since sales demand eventually governs production, it is necessary to know the number of units of the product to be manufactured. The unit of product is usually the lowest quantity sold; such as electric motor, garage door, or ream of typewriter paper is the usual basis for estimating sales. The planning engineer, however, must work with the elemental parts or components in product analysis. In this formative stage of production, a great amount of detail analysis is necessary as preparations and plans must be made for purchasing material, machines, engaging men to carry out plans and providing money. Analysis of the components of a product allows certain questions to be answered:

1. What material and how much enters into the manufacture of each component?
2. What parts are combined into sub-assemblies and finally into completed assembly?
3. What parts are to be made and how many go into one unit of the finished product?
4. What parts are to be purchased and how many go into one unit of the finished product?
5. What stocks and sundries, such as, nuts, bolts, washers and screws, enter into the sub-assemblies and final assembly?

Materials

Materials provide the starting point for most of the thinking and all of the work done in production. Often a part may be made from one of several materials. Many times a casting may be made from aluminum or gray cast iron; a gear wheel can be made from brass rod or casting, with the teeth cut after machining the blank, or from a zinc die casting with the teeth cast. Choice of material largely depends on quantities required, and the material cannot always be specified until after the method of processing has been settled.

Bill of Materials

When all of these factors have been determined, the amounts of material of a certain kind and grade required for the part can be listed. This list is commonly called the bill of materials. There is no standard form which this list must follow; the length and form will vary depending upon the product to be made. Figures 2-1, 2-2, and 2-3 are examples for various products, a truck bed, a loaf of bread, and rolled wire glass.

After completion of the bill of materials, down to the smallest screw, bolt, and nut called for by the drawings and the material specified, an analysis is made showing:

1. Parts to be purchased in finished condition.
2. Parts to be manufactured.

It is often considered more desirable to purchase certain components than to make them. Some of the factors to be considered in making this decision may be:

1. Cost - Many items may be purchased more cheaply than they can be manufactured.
2. Tolerances - Greater accuracy can be obtained in your own plant than in an outside plant where less control is possible.

Operations

After the amount and grade of every kind of material have been settled, the next two steps are as follows:

1. Requisitions for purchasing are made out for (1) material required - in determining material required, care must be exercised in determining allowances for waste, spoilage and loss of product between operations - and (2) finished parts to be purchased.
2. An operation sheet for each part to be manufactured in the plant is made. This must include methods, processes, sequences, tools, and fixtures. It assigns, tentatively,

BILL OF MATERIALS

Truck Bed

The following is a complete list of all materials required for the construction of the utility truck bed and its accessories. All parts which are to be made in the shop from structural steel are made from SAE 1020 steel.

A Frame

Part Name	Material	No. Rqd. per Body	Weight Lb.	Cost
Runners	3/16" 1020 11" x 9'7"	2	131.6	$ 10.52
Z Beam	1/8" 1020 10" x 6'7"	2	56.0	4.49
Side Plate	1/4" 1020 6'7" x 9 1/8"	2	99.0	7.92
------	------	------	------	------
------	------	------	------	------
------	------	------	------	------
------	------	------	------	------
Bolster Boss	2" OD Pipe	1	.6	.05
Flooring	2" Oak	49 sq.ft. @ .22/ft.		10.78
Carriage Bolts	3/8" x 3"	10		.10
Total				$ 85.65

Weld Metal Disposition

Operation	Ft. of Weld	Lb. Weld Metal
Headache Rack ·	30	7.5
Winch Bracket	3	.75
A Frame	1	.25
Gin Poles	1	.25
Bed Frame	51	13.0
Roller Assembly	15	4.0
Total		25.75

Total Cost @ \$.08/lb. = \$ 2.06

Figure 2-1

BILL OF MATERIALS

Recipe for Baker's Choice Bread

This recipe contains the percentage by weight, weight in ounces per ingredient per loaf, and cost per ingredient per loaf for Baker's Choice Bread. In computing the ingredient cost per loaf, the cost of water is omitted. Total water usage for the entire plant being added to all costs at accounting intervals with water costs being paid monthly. Figures are based on an 18 ounce dough weight per 16 ounce loaf in order to take up evaporation losses in the oven. This 18 ounce basis is also used in calculating storage space.

INGREDIENT	PER CENT BY WEIGHT OF 18 OUNCE DOUGH	ACTUAL WEIGHT IN OUNCES	COST PER LOAF
Flour	60.000	10.8	$.0441
Shortening	2.375	.4275	.0078
Milk	4.375	.7875	.0049
Salt	1.375	.2475	.0015
Sugar	1.75	.315	.0020
Yeast	1.375	.2475	.0010
Water	28.375	5.1075	
Arkady	.375	.0675	.003
	100.00	18.0000	$.0616

Figure 2-2

BILL OF MATERIALS

Roller Wire Glass

Original Wt.	Material	Fusion	Loss	Weight	Silica	Lime	Soda	Mag.	Alum
1000	Sand	none	-	1000	1000.				
330	Soda	44.2	145.9	184.1			184.1		
30	Sodium Sulfate	56.5	17.0	13.0			13.0		
194	Calc Limestone	44.2	85.7	108.3		108.3			
128	Dolomitic Limestone	46.0	58.9	69.1		41.4		27.6	
15	Feldspar	none	none	15.0	9.9		2.3		2.7
3.5	Borax	44.2	1.5	2.0			2.0		
1700.5			309	1391.5	1009.9	149.7	209.4	27.6	2.7
					72.6%	10.7%	14.5%	2%	.2%

Figure 2-3

setting-up and operation times.

If the planner of the industrial plant is not familiar with the work involved in step No. 2, he may secure the needed information from any of several sources. He may compare his ideas and plans with other companies who have experience in the same or similar lines. This may be done through correspondence or personal contact, or he may contact the state and federal governments for information concerning such an enterprise. Many books are available in libraries giving the required information or methods of calculating such. Salesmen and sales engineers of equipment manufacturing companies are a valuable source of information. They not only know their own product but through their contacts with many diversified industries can enlighten the man just starting out on several of the obstacles with which he will be confronted. In the preparation of the operation sheet, calculations and estimates must be submitted in detail and must be accompanied by supporting reasons.

Major Sequences

At first it is desirable to list only the major sequences through which each part of the product must pass, including sub-assemblies and final assemblies.

Minor Sequences

Then the planner must go through his general analysis and add the minor operations necessary.

Details

Finally the details are added. Such details might include hand-burring of sharp edges after a machining operation, washing or degreasing machined products just prior to painting, or hand sanding an end table between coats of varnish.

In brief, the operation sheet should describe in the greatest possible detail each operation and instruments with which they are performed.

Such information should include:

1. Description of operation.
2. Facilities to perform it.
3. Alternate facilities if any.
4. Part number and name.
5. Economic lot size.
6. Special jigs and fixtures.
7. Auxiliary tools and templates.
8. Material specifications and ordering data.
9. Machine feeds and speed.
10. Drawing of operation.
11. Standard time.
12. General instructions.
13. Specific instructions.
14. Weight per piece.
15. Yield in case of cutoff material.
16. Revision record.
17. Sheet number.
18. Number of sheets to operation.

Figures 2-4 and 2-5 are examples of different types of operation sheets.

Plan each operation in the most elemental terms using simple purpose production machines and tools. When this is accomplished the operations that are necessary to produce a good part will have been determined. Production demands will then dictate the combination of operations using special machines or special tools.[1]

---

[1]*Better Methods in Work Standards*, p. 20.

OPERATIONAL DESCRIPTION

Truck Bed

Dist (ft)	Time (min)	Description
15	2	Sheet stock is lifted from storage rack by the overhead crane and placed on layout table by shear operator and assistant.
3	2	Sheet stock is laid out to best advantage by shear operator and assistant. Plate is positioned by hand in shear by rolling on roller-top layout table. Plate is cut to correct size for runners.
15	1	Piece falls out back of shear automatically and is placed by hand into rack adjacent which also serves as pre-storage for brake operation.
--	-	--
53	2	Two channels are loaded on assembly rack along with other parts necessary to make one bed. Rack is moved to assembly area and placed near assembly jig by means of a fork truck.
		Assembly rack, containing channels (runners) is stored at jig prior to assembly.
(See Frame Assy)		Runners are taken from rack and carried to jig by hand. Operation performed by assembly operator and assistant.
" " "		Runners are placed in position on jig by operator and assistant. Jig is set to correct width and governs position of runners.
" " "		Assembly operator and assistant weld five pads to each runner. Runners are then reversed in jig. Time includes preparation time for welders.

Figure 2-4

Date	Page 1 of 1 Truck #2
Operation:	Trucking Pallets of 24/1 and K.T. Cases from Filling Line to Storage
Department:	C&P

Job Description

Full pallets of cases are picked up by lift truck and carried to spot in storage. Life truck return to line.

No.	Element	Element Description	Rest Allowance	Work Minutes
1	Load Pallet	Truck picks up loaded pallet Start: Fork under pallet Stop: Start to back up	18	.1062
2	Transport and unload	Truck takes pallet to storage space and releases Start: Start to back at line Stop: Start to back at storage	18	.6738
3	Return from storage	Truck returns empty Start: Start to back Stop: Fork under pallet	18	.4590
		Work minutes per pallet		1.239

Standard hours per pallet = .02065

Standard production = 48 pallets per hour

Figure 2-5

Process Analysis

Probably the easiest way to make a complete analysis is to construct a process chart.

The process chart, (See Figures 2-6 and 2-7), is a schematic representation of a process showing:

1. The relationship of various materials, parts, and sub-assemblies.
2. The sequence of operations on each part or material.
3. How and at what point in the process the materials come together.
4. What handling is required and how it is done.
5. At what points storage facilities are required.

This chart aids in simplifying processes and methods by giving a complete graphic picture of the process and by requiring one to study and plan the process in detail in order to obtain the data for the chart.

The process chart does not show a physical arrangement of departments or equipment, however. It is comparable to the wiring diagram of a radio set, which shows connections and the flow of current but not the arrangement of the parts. It usually begins with the raw materials as they enter the plant and follows them through every step of the manufacturing process until they become either a finished unit or part of a sub-assembly.

By studying the chart carefully, it is freqnently found that machines may be purchased to permit combining operations, and delays between operations may be eliminated. The process chart assists in showing the effects that changes in one part of a process will have on the other parts.

How the Chart is Made

Frank B. Gilbreth and his wife, Lillian M. Gilbreth, the founders of Motion Study, were the originators of the process chart symbols. In the origi-

PROCESS CHART

RECEIVING STORING AND DELIVERING FLUX TO HEAT-MELTING MIXING AND POURING MOLTEN ALLOY

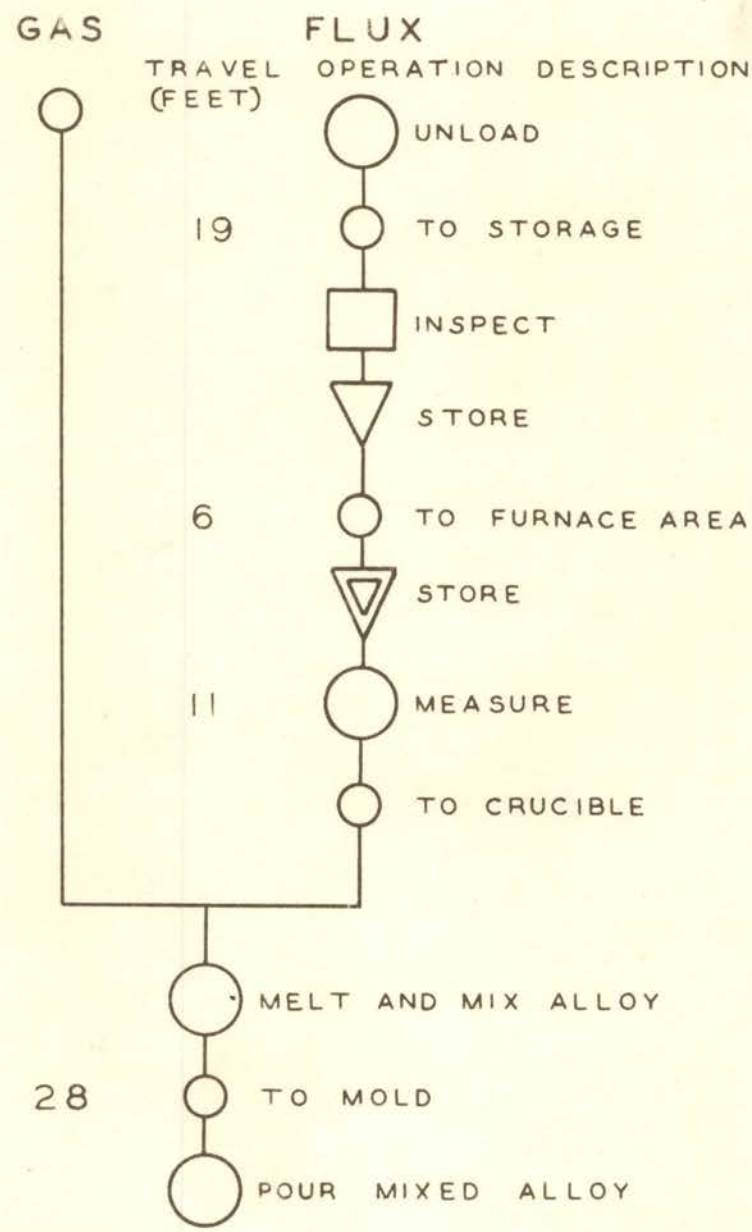


Figure 2-6

PROCESS CHART

PACKAGING AND SHIPPING 100-POUND GREASE DRUMS

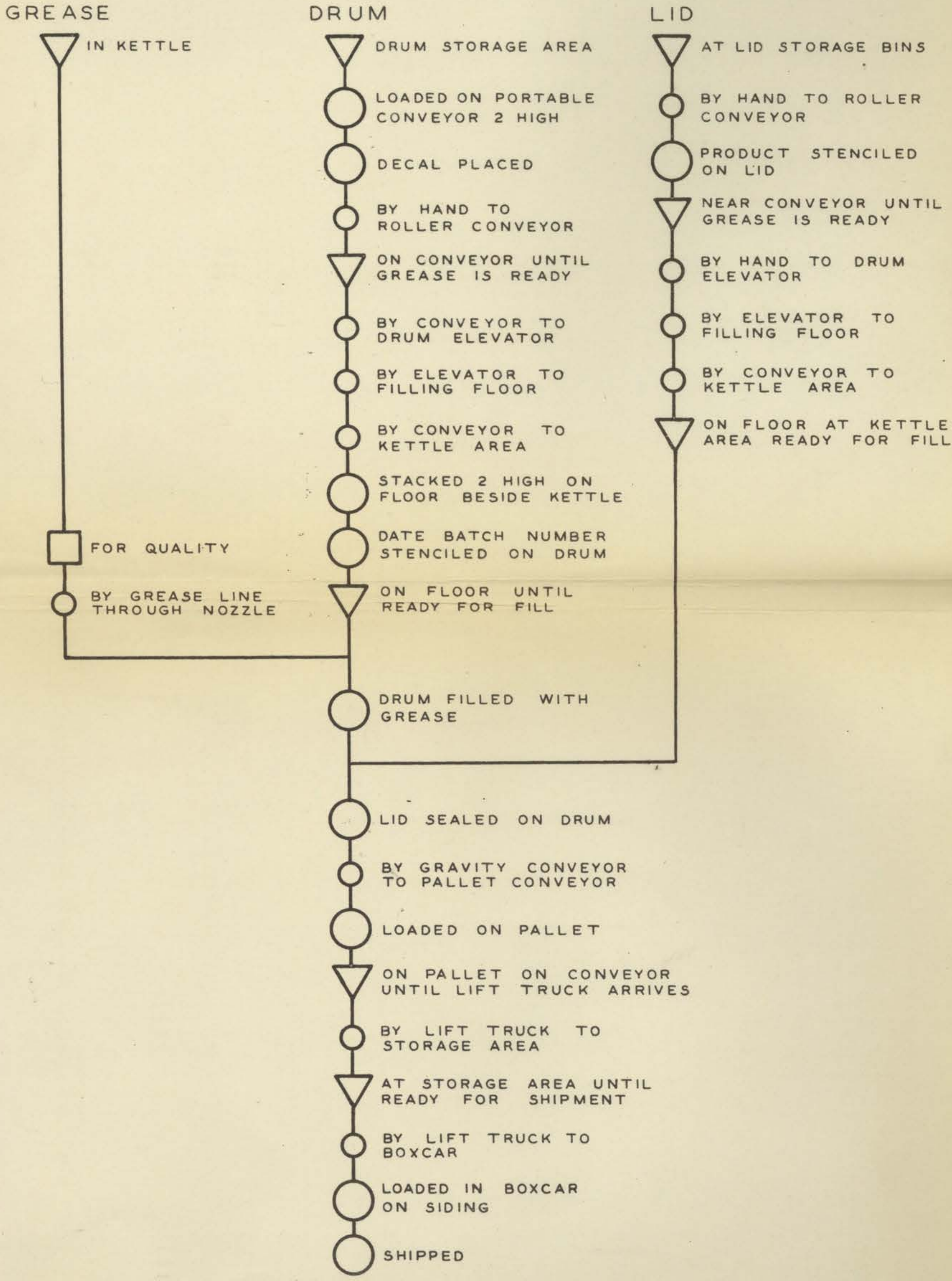


Figure 2-7

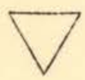
nal list there were 40 symbols, however, it has been found that five basic symbols are adequate for describing most any production process.

An explanation of these five symbols along with the method of preparing process charts follows:

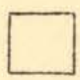
1. Each series of steps is represented by a series of symbols arranged in a column. Use of these generally accepted symbols, shown below along with their definitions, makes it easier to construct a chart. One can glance at each symbol and identify the operation.

   
   An operation occurs when an object is intentionally changed in any of its physical or chemical characteristics or when it is prepared for another operation, transportation, inspection, or storage.

   
   A transportation occurs when an object is moved from one place to another, except when such are caused by the process or by the operator at the work station during an operation or inspection.

   
   A permanent storage occurs when an object is kept and protected against unauthorized removal.

   
   A temporary storage occurs when an object is kept but not protected against unauthorized removal.

   
   An inspection occurs when an object is examined for identification, verified for quality or quantity, or measured in any of its characteristics.

2. Explanatory data more or less detailed, as desired, covering the following may be entered on the chart:

Operation	What is done. What machine is used. Who performs the operation: automatic or manual. How is it done as to capacity, speed, time.
Transportation	Where the material goes. How is it transported, machine or manual. Quantity moved in each load. Time required.
Storage	Why is it stored. Where stored.

How stored (on floor, shelves, pallets, bins).
Length of storage.

Inspection	Purpose of inspection. Who does it. Where is it done. Time required.

3. Variations may be made in the form of the chart used. Imagination should be exercised in adapting charts to particular problems, such as:

   Different colored lines for various parts and materials.

It will be seen that if a process chart is properly constructed, the result will be a recorded plan of all of the steps necessary in the production of a part.

Each operation will have been listed; every move will have been planned; and the over-all material handling method will have been specified for use in determining needed equipment and making the plant layout.

Making the process chart causes the planner to think of many of the problems of plant layout long before that stage of planning. Too, it provides a simple means for checking details which might cause serious trouble and many hours of time at a later date if overlooked in the planning stage.

<u>How the Chart is Used</u>

The following are a few uses of process charts:

1. For Layout - As a preliminary step to plant layout.

2. For Training - As a guide to plant operators to help them visualize complex processes more readily.

3. For Gathering Costs - As an aid in building up cost data for a particular product.

4. For Process Improvement - As an aid in visualizing what is to be required in the manufacture of a new product and in comparing alternative processes.

5. For Office Layout - As a guide in analyzing office and clerical procedures as well as manufacturing processes.

CHAPTER III

DETERMINATION OF MACHINE REQUIREMENTS

Production consists of operations by men and machines on material. When necessary information as to material and methods of manufacture has been developed, the next step is to acquire equally accurate information as to the capacity of the machines to operate on the material. This information is secured by what is known as machine analysis.

Obviously, certain, fundamental questions must be answered:[1]

1. How long will a particular machine take to perform its operation on a unit quantity of material?

2. How many units of each variety of material can be produced on this machine per day, week, or month?

3. What is the maximum plant capacity per day for each process on each variety of material?

These questions may be answered by actual experiment and trial, by records of past performance, by guessing or estimating, or by information secured from the manufacturers of the machine.

Answering the first question, will necessitate determining (1) how long does it take to make the machine ready for a new job - set-up time, and (2) how long does the machine take to perform the actual operation on a unit quantity of material once it has been set up - operation time.

The set-up time is not easily determined or standardized in many cases. In setting up a printing press it is necessary to have the ink, paper, speed, pressure, all mutually adjusted. To set-up a machine tool may involve special jigs or fixtures and the establishment of cutting feeds and speeds.

---

[1]L. P. Alford, and J. R. Bangs, Production Handbook, p. 108.

Other processes may involve feeding material into a hopper for the entire set-up.

The operation time is capable of fairly exact predetermination.

Strict adherence to the operation sheet is necessary in selecting machinery for a plant. Occasionally, a machine is found that will eliminate some work by combining operations. Care must be taken to select a machine that will do what is called for by the processing and do it in the time allotted.

One of the most difficult problems to be solved is that of balancing the capacity of the production line. At this stage of planning, the principles of the Gantt chart are helpful. It is generally recognized that bottle-necks are the most serious hinderance to economical production. If machines are not perfectly balanced and loads identical, then it will be necessary to create storage space to take care of the unbalanced production of parts.

Start balancing by using the operation sheet. From the list of parts entering into the product together with the quantities of each and the rate of production necessary for each series of operations, the proper line balance may be determined.

Example

> Machine requires a given number of pieces per minute (50) but these pieces must be assembled by hand prior to machining at a lower rate (10 pieces per minute); thus five persons are needed to keep up with the machine.

The number of machines required depends on the capacity or output of the plant and the time required to perform the various operations involved in the manufacture of the product. When the unit time (operation time plus the set-up time) has been determined and multiplied by the daily output, it is a simple matter to divide into this minutes per day.

Formula

$$\text{Number of machines} = \frac{\text{Unit time x Daily output}}{\text{Minutes per work day}}$$

Factors Influencing the Initial Selecting of Machines

The following is a summarization of data to be gathered and considered before selecting machines:[2]

1. Type of operation.
2. Operation requirements.
3. Quantity to be produced.
4. Output per hour.
5. Cost of tooling.
6. Set-up and tear-down time.
7. Life of machine.
8. Cost of machine.
9. Cost of labor to operate.
10. Type of production.
11. Maintenance cost.
12. Flexibility of machine.
13. Floor space.
14. Weight.
15. Future business trend.
16. Material to be worked.
17. Similar machines availability.
18. Type of plant layout.
19. Head room.
20. Material handling facilities.
21. Illumination requirements.
22. Power.

---

[2] Economics of Tools and Equipment, p. 24.

23. Machine hazards.

Final Selection of Machines

After the preceding factors have been considered and a number of tentative machines have been selected, a specific machine to be used for an operation must be selected. In determining the make and model of the machine, the following is a guide covering several important factors that should be considered. There are probably other factors which may also be important but those listed are representative.[3]

Cost Factors

1. Investment.
    a. Initial cost of machine.
    b. Cost of accessories.
    c. Installation.
    d. Depreciation.
2. Operation.
    a. Upkeep and repairs.
    b. Supervision.
    c. Power.
    d. Wages of operator.
3. Final.
    a. Hourly charge when idle.
    b. Hourly charge when running.
    c. Normal production per hour.
    d. Unit cost of production.

Design Factors

1. Materials of construction.

---

[3]*Ibid.*, p. 26.

a. Kind used for different parts.

b. Distribution of metal.

c. Strength and stability.

2. Power.

a. Is it abundant?

b. How is it applied?

c. Is control centralized?

d. Are heavy parts power moved?

e. Is direct motor mounting provided?

3. Lubrication.

a. Forced? Sight feeds used?

b. Are oil holes accessible?

c. Oil and grease cups on bearings?

d. Gears run in oil bath?

4. Bearings.

a. Ordinary.

b. Ball bearings.

c. Roller bearings.

5. Chucking.

a. Ordinary.

b. Magnetic.

c. Air controlled.

6. Safety.

a. Machine.

b. Operator.

7. Speed changes.

a. Number and ratio.

b. Quickness of change.

8. Operation.

    a. Friction.

    b. Vibration.

    c. Ease of feeding and discharging.

    d. Self-helping attachments.

9. Repairs.

    a. Are wearing parts interchangeable?

    b. Accessible and easily changed?

10. Miscellaneous.

    a. Facilities for quick set-up.

    b. Other kinds of work possible.

    c. Is it easily movable?

    d. Rigged for using cutting lubricants.

    e. Fit location available.

CHAPTER IV

MACHINE LOADING CONTROLS

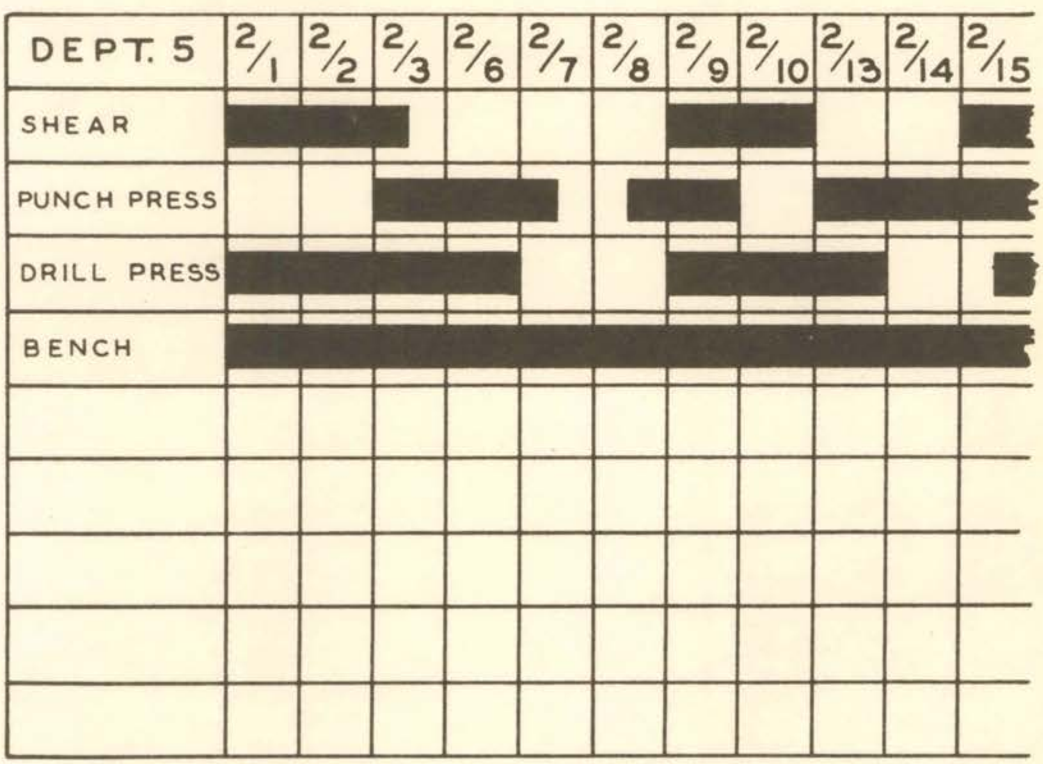
The procedure for determining machine loading and scheduling is the same whether it is for one part to make up an entire job, or whether there are ten or one hundred parts required to make up the complete finished product. It is simply a matter of following the break-down of parts and sub-assemblies as shown by the blueprints and drawings. Each part must be scheduled as a separate unit and followed through as though it were to be the finished product; also a sub-assembly is scheduled as though it were a separate unit.

Some mechanism should be provided to record machine loading. The particular form or mechanism used is a matter of choice. Probably the oldest form in use is that of the Gantt chart. It has the advantage of giving the overall picture at a glance (visual control).

The Gantt chart in Figure 4-1 may be prepared using standard graph paper. There are boards on the market that use the Gantt principles, and are operated by inserting suitable tickets in their proper places on the board. When changes become necessary, it is merely a matter of changing the location of the tickets whereas with the paper chart each change means erasure. Referring to Figure 4-1, as jobs are planned for the machines listed, the chart is blocked out opposite the machine for the days or parts of days the machines are to be in use. The spaces that are not blocked out indicate idle time for that machine.

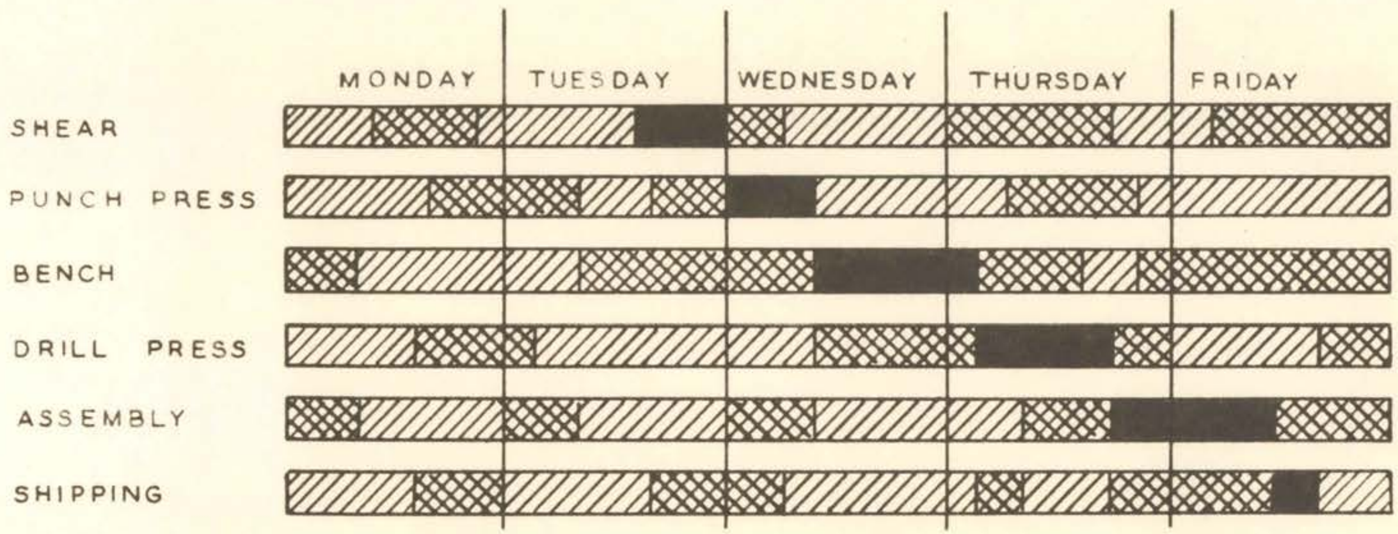
The Gantt chart in Figure 4-2 shows how one part may be intermingled with other parts. Each part is indicated by a marking system, and even though it is intermingled, the parts may be located at all times.

Examples of loading charts may be found in the Production Handbook by L. P. Alford and J. R. Bangs showing labor working without machines.



GANTT LOAD CHART

Figure 4-1



GANTT LOAD CHART

Figure 4-2

CHAPTER V

FLOW CHARTS

In the planning of a plant layout the use of a technique called a Flow Chart which visually portrays the path of a part from machine to machine is very helpful. This chart presents diagrammatically on the plant layout the same steps that are shown on the process chart. The flow chart may be made from information taken from the process chart, or it may be developed independently as a means of gathering information on a process.

By use of this tool, the planner can tell at a glance if there is "backtracking" or any unnecessarily long moves in the proposed layout. The merits of a proposed layout can be quickly visualized or appraised.

The flow chart is distinguished from other work representations by the fact that the path of the object in question is pictured in relation to the area or space in which operations on the object take place. In producing such a picture, the main consideration is the basic flow of the product, i.e., the nature of production, space required for efficient handling and moving of the objects under consideration, methods of handling materials and parts, and the locations of various fixed facilities.

The flow chart may be made on a layout or on a transparent overlay. The second method is very desirable when too much information is already marked on a layout or there is a need to show the flow of several parts through one area.

Guides for Developing a Flow Chart

The layout engineers in many industries have worked out guides to assist in the developing of flow charts. The following is a recommended list of items that are used in the layout engineers' training program at the General

Motors Institute:[1]

1. Determine an effective location in the area for each piece of equipment involved in the process and indicate it on the layout.

2. Indicate on the layout near the planned point of occurrance each process symbol listed on the process chart.

3. Number each symbol the same as the symbols on the process chart.

4. Join the symbols with a line, placing an occasional arrowhead on the line to indicate direction of flow.

5. Identify the flow chart and indicate on it any information relative to the process.

Developing the Flow Chart

In developing a flow chart, a basis for the type of flow indicated must first be selected. This may be similar to one of the typical examplės depicted on the accompanying diagrams or may involve a combination of several of these. These typical bases are in order: (See Figure 5-1)[2]

1. Direct straight line flow.

2. Circular flow.

3. General flow.

4. Direct flow not following a straight line.

Upon selection of the basis, decide which type chart to prepare. Flow charts fall into the three following definite kinds:

1. Three dimensional models showing the building or work area, machines, and facilities to scale together with a layout of persons or products.

2. Three dimensional views of all or part of the building or area under consideration together with the path of persons or product.

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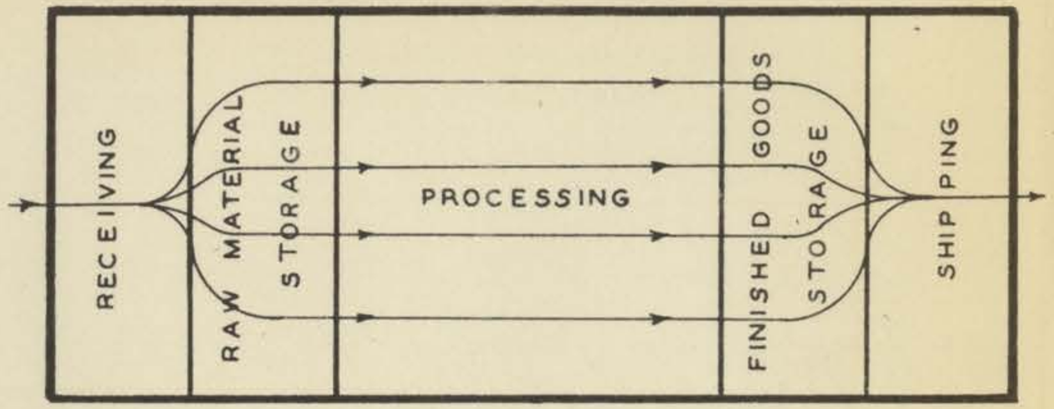
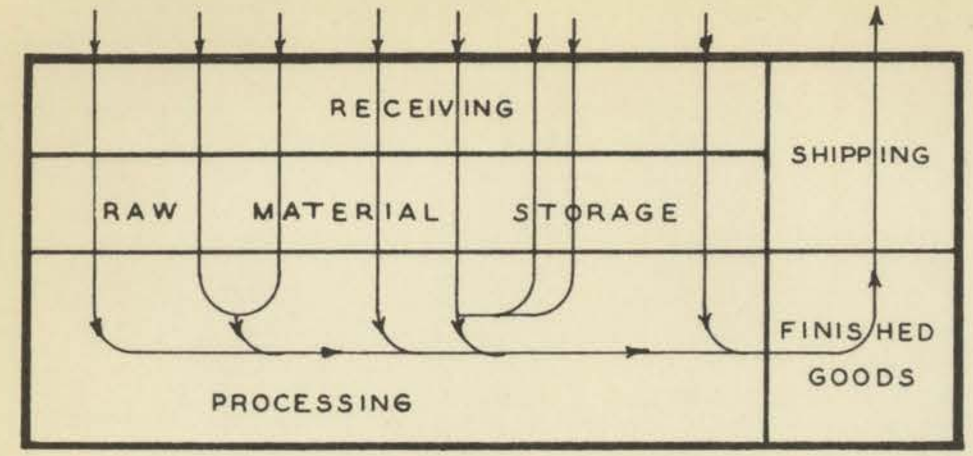
[1]Methods and Processing, p. 72.

[2]R. M. Barnes, Works Methods Training Manual, pp. 213-214.

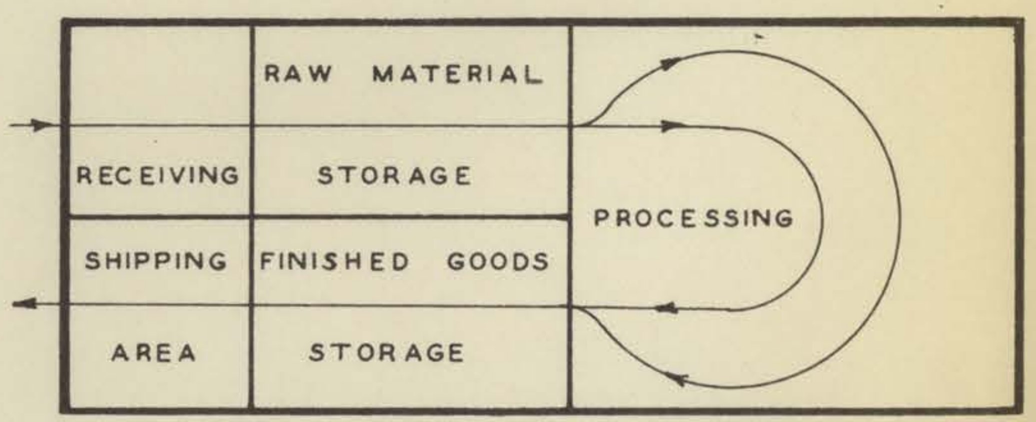
TYPES OF FLOW



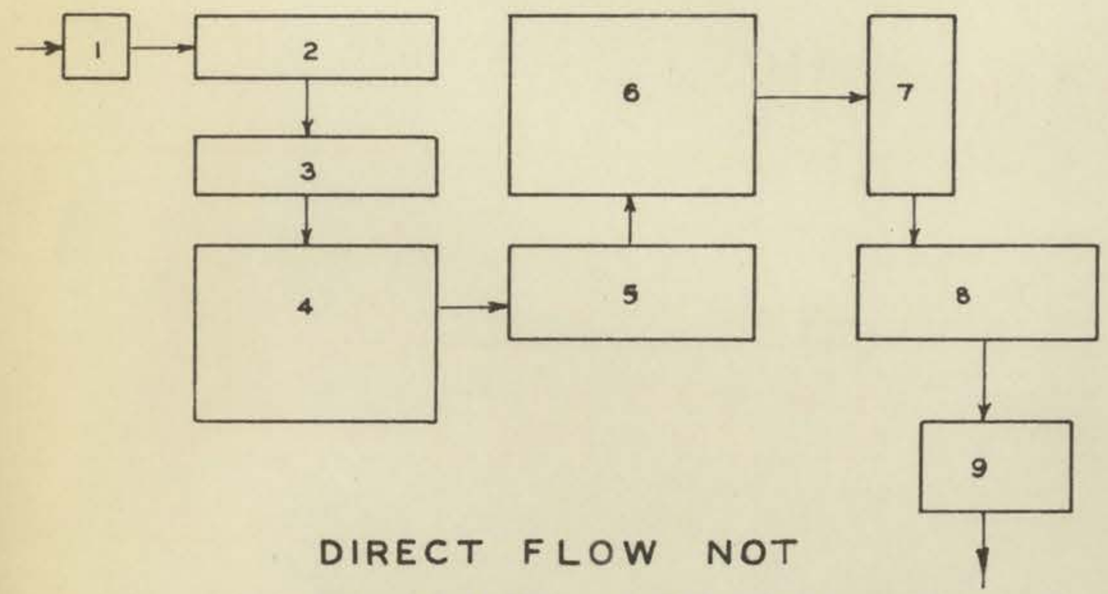
DIRECT STRAIGHT LINE FLOW



GENERAL FLOW



CIRCULAR FLOW



DIRECT FLOW NOT FOLLOWING DIRECT LINE

Figure 5-1

3. Two dimensional views of the foregoing work places and objects.

The purpose behind each of these examples is to provide an over-all view of the path of an object by indication of the key points involved and the sequential relationships between these points, thus affording a comparison of ideas relating to efficient work arrangement before actual physical placememt of equipment is involved. By means of a flow chart, attention is quickly focused on "back-tracking", crisscrossing, and excessive transportation distances, thereby indicating possibilities for better layout.

An example of a poor machine arrangementsand a good machine arrangement is shown in Figure 5-2 and 5-3.

The same procedure and care used in planning a flow diagram for the manufacturing plant should be exercised in selecting the arrangement of office equipment and facilities. Figure 5-4 presents examples of a poor arrangement and a good arrangement for office layout.

Proper planning will result in an increase in production, more efficient methods of production, and the employees will have a better place to work and will be able to do their work with less effort.

Improvements by proper analysis of proposed layouts will result in:

1. Reduced manual handling - The installation of all types of conveyors will practically eliminate all manual handling.

2. Reduced storage space - Work in process may be stored "in transit" on overhead conveyors from receiving room to assembly. Spiral conveyors used to carry miscellaneous parts directly to assembly where they may be stored in hoppers suspended from the ceiling. This would also eliminate the confusion that normally results from numerous totepans and floor bins.

3. Reduced production space - More efficient arrangement of machines may allow one operator to service more than one machine.

4. Reduction of waiting time - By assuring a constant supply

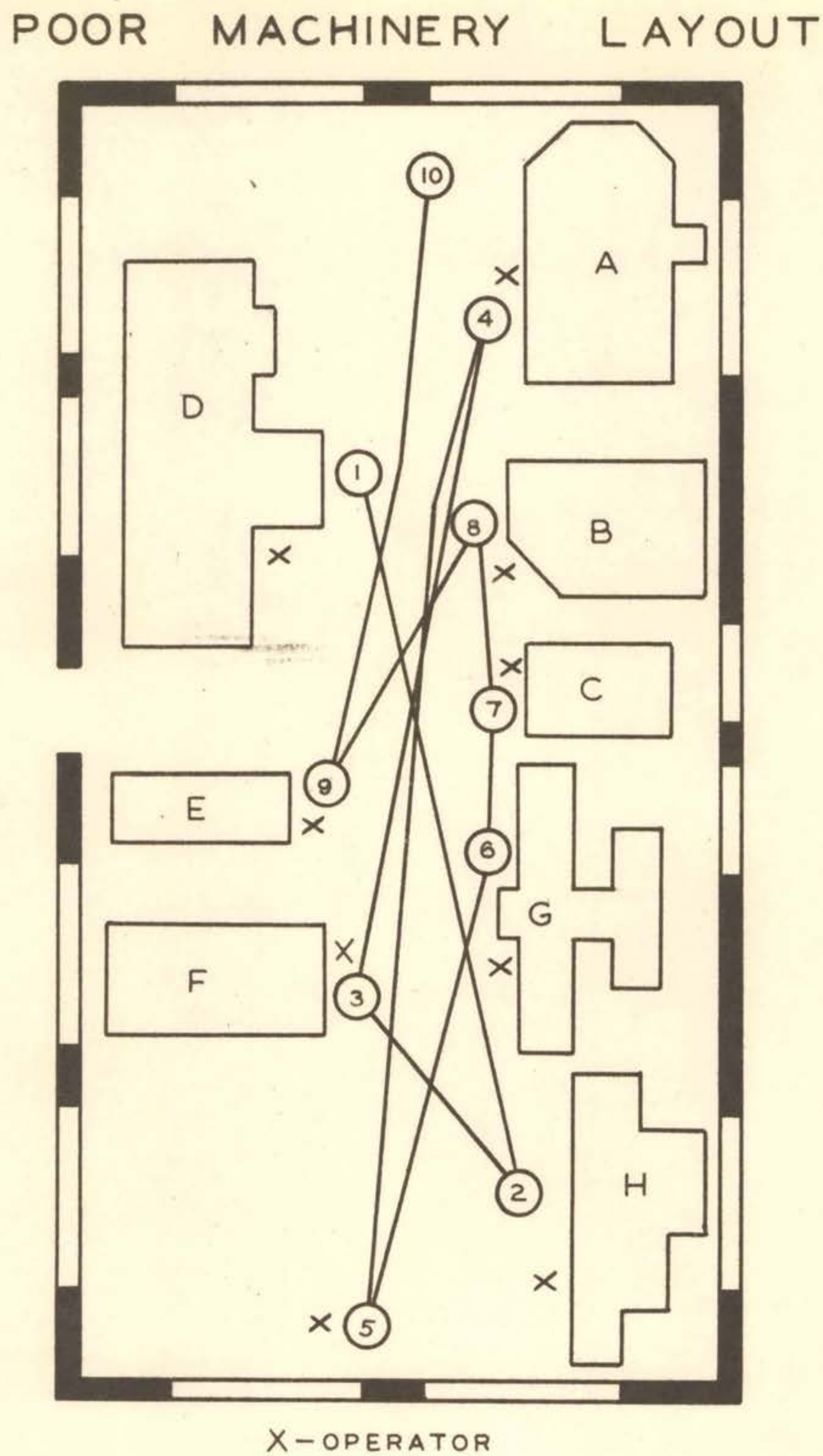


Figure 5-2

GOOD MACHINERY LAYOUT

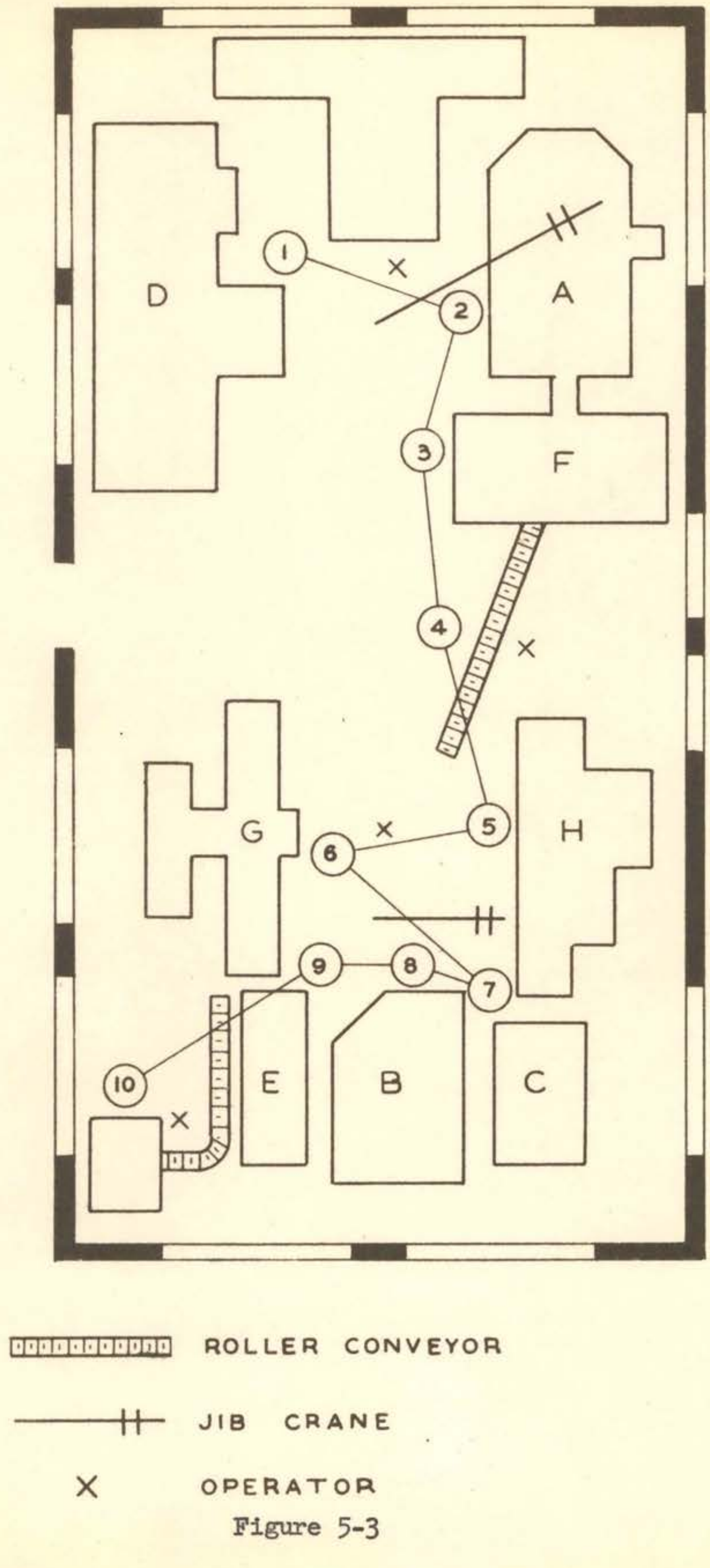
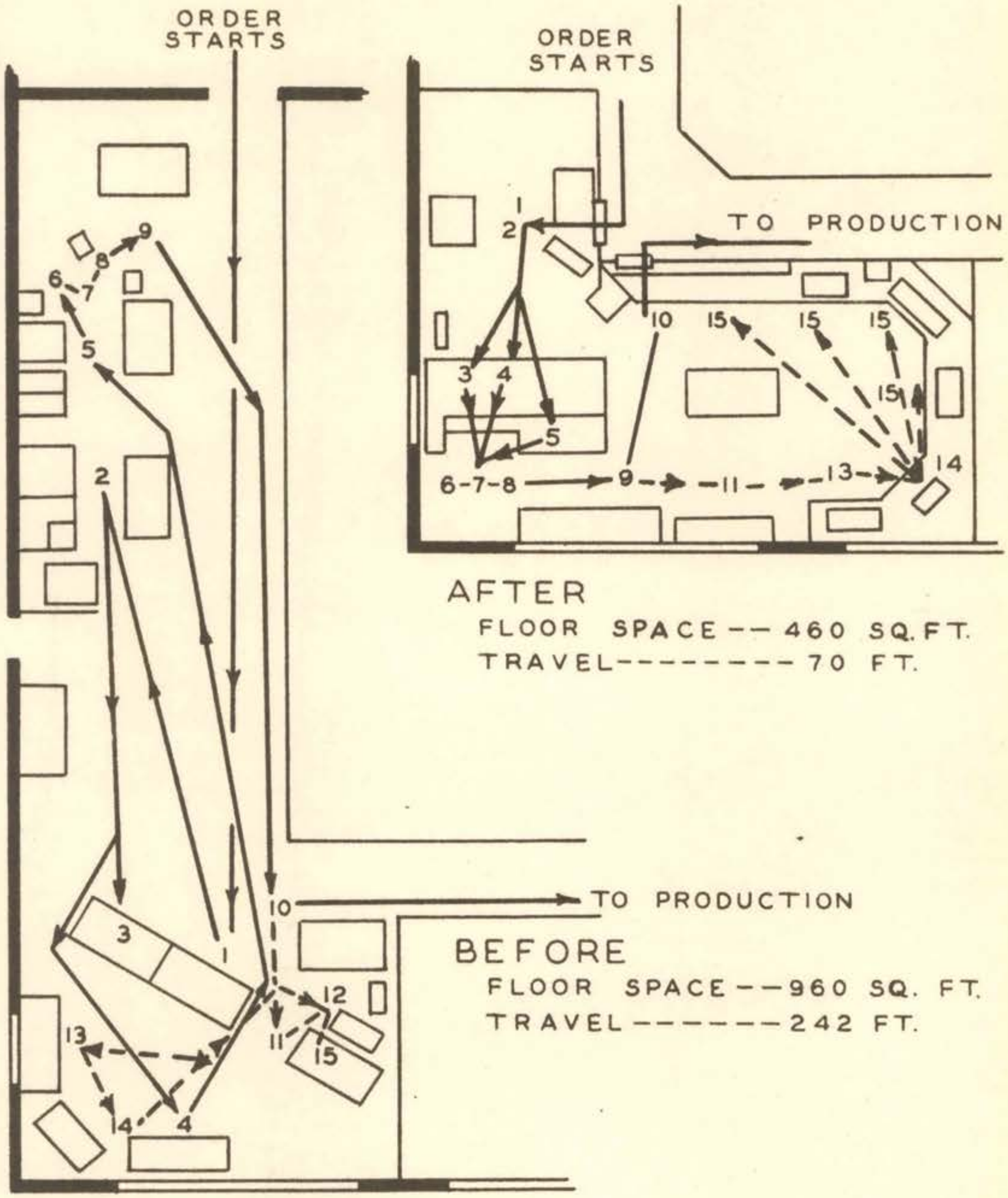


Figure 5-3



PROPER ARRANGEMENT OF DESKS

Figure 5-4

of parts at the work stations, machines and personnel seldom have to wait. Careful planning and scheduling of material flow is needed to prevent lost time by materials, machines and personnel.

5. Reduced inventory - The planning, scheduling, and in-process storage made possible by proper layout will result in marked savings in inventory. It is possible to meet production requirements with a minimum supply of material on hand at any point in the plant. If possible, material flow should begin at the main storesroom - or, where possible, at the receiving dock - and should continue until the final, crated product is ready to go to storage or to the shipping dock.

Analyzing The Layout and Flow Diagrams

After or during the analysis of the process charts, the plant layout and flow diagram should be studied in detail along the following lines:

1. Analysis of layout.

    a. Flow diagram of proposed processes.

    b. Flow space tabulation and summary. (See Chapter XII).

    c. Equipment needed. (See Chapter III).

    d. Storage facilities. (See Chapter VII).

2. Equipment requirements.

    a. Space should be allocated in the layout for anticipated future production which would require more machines.

    b. Production quantities of each product should be estimated separately.

    c. Based on estimated production volumes, it is necessary to establish production rates for the various operations in order to calculate the machine hours required per week to meet the anticipated requirements.

3. Storage requirements.

    a. The required storage capacity should be determined.

4. Working conditions.

    a. Requirements for adequate lighting. (See Chapters XIV and XV).

    b. Temperature, humidity, and ventilation. (See Chapter XIII).

    c. Noise, vibration, and dirt.

d. Plant housekeeping.

Examples of Flow Diagrams

Figures 5-5 and 5-6 show the general layout where materials handling was the major problem in the manufacture of electric tools.

Figure 5-7 shows the layout of the packaging and shipping room and the sequence of operations in packaging and shipping a 100-pound grease drum. This flow diagram was prepared by super-imposing the process chart symbols in the layout chart.

Figure 5-8 shows the layout of a plant manufacturing oil field truck beds.

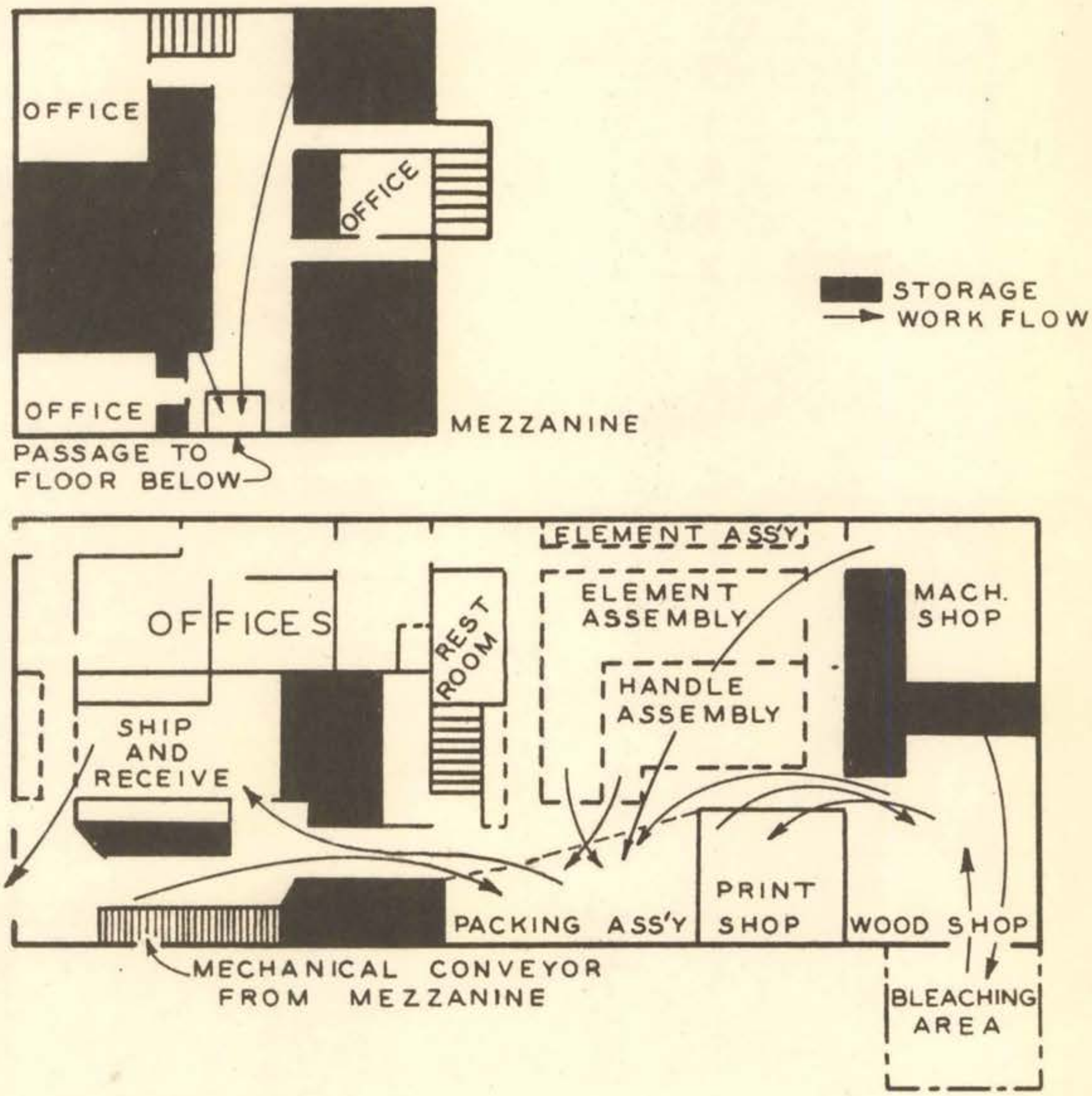
Figure 5-9 shows continuous-flow finishing in a Multi-story building. This diagram is for finishing wood furniture.

Advantages of a Flow Chart

The developed flow chart has many uses.[3]

1. It aids in presenting facts or plans to others.
2. It helps to point out areas of improvement.
3. It graphically portrays material handling plans.
4. It aids in the reduction of material handling by pointing out "back-tracking".
5. If the process chart has been made first, it serves as a check.

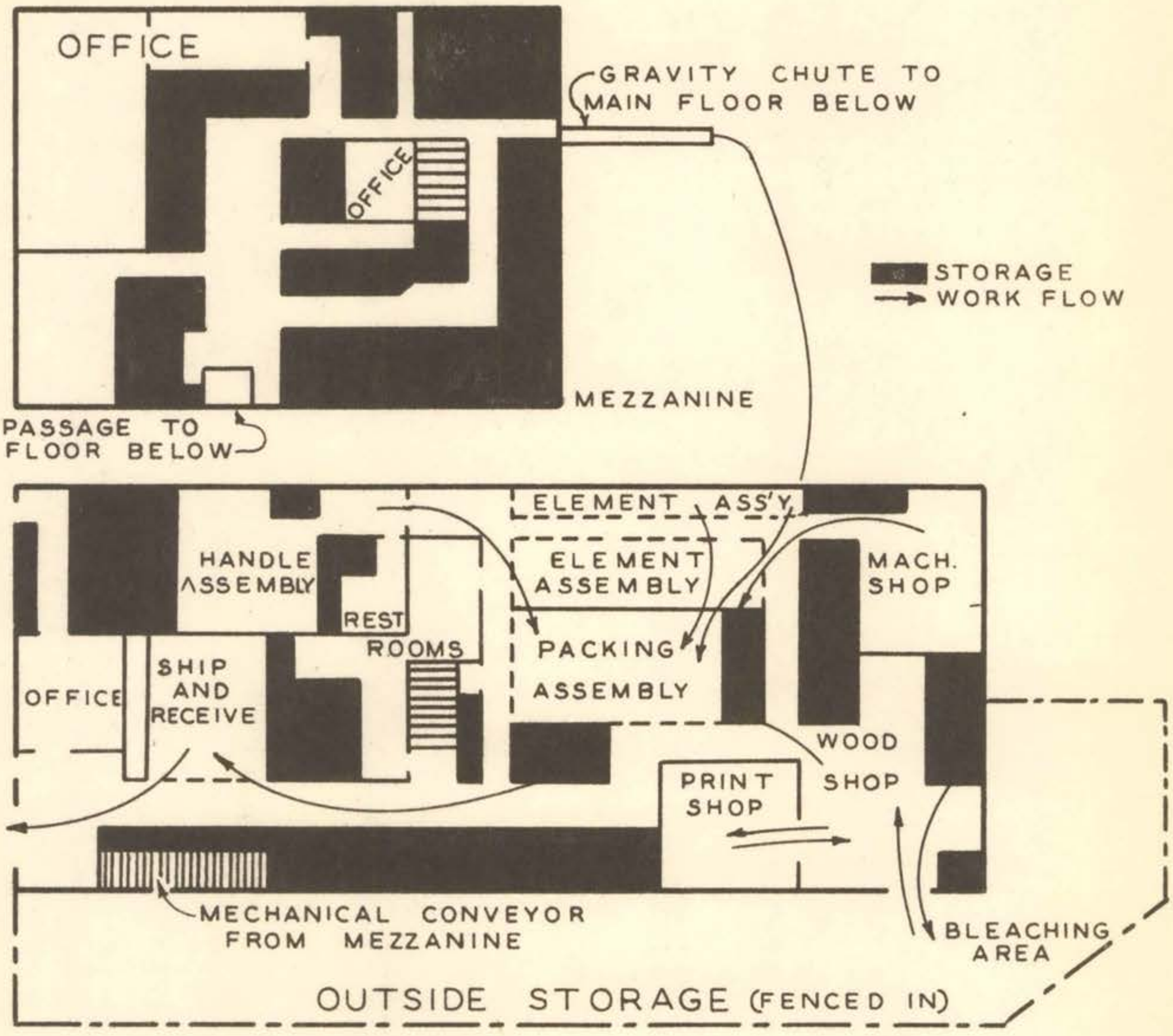
[3] Methods and Processing, p. 73.



OLD LAYOUT

MANY FLOW LINES – NUMEROUS CROSS-OVERS – WASTEFUL BACK-TRACKING

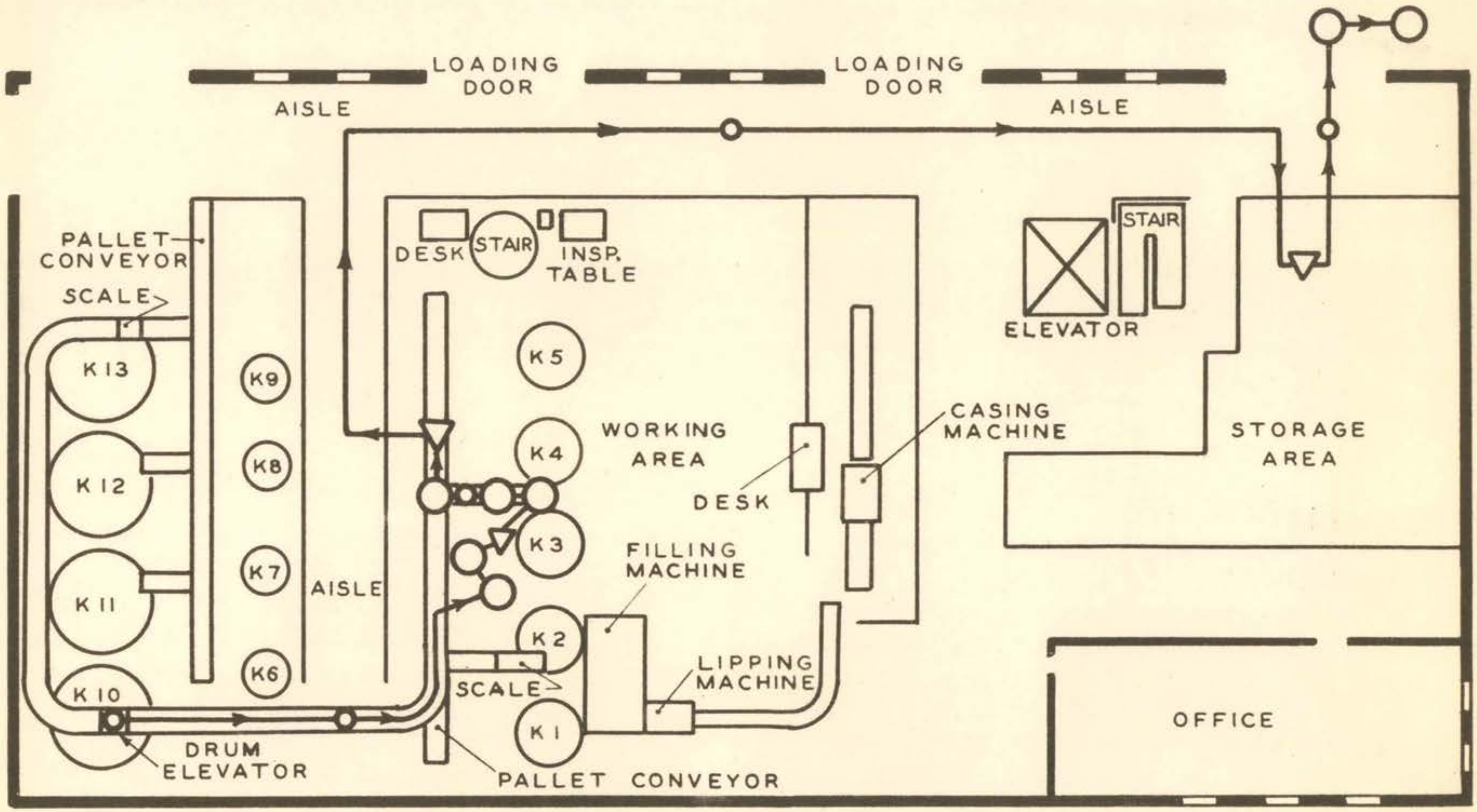
Figure 5-5



NEW LAYOUT

FEWER FLOW LINES – FEWER CROSS-OVERS – LESS BACK-TRACKING – BETTER PLACED AISLES

Figure 5-6



FLOW CHART

PACKAGING AND SHIPPING 100-POUND GREASE DRUMS

Figure 5-7

FLOW CHART

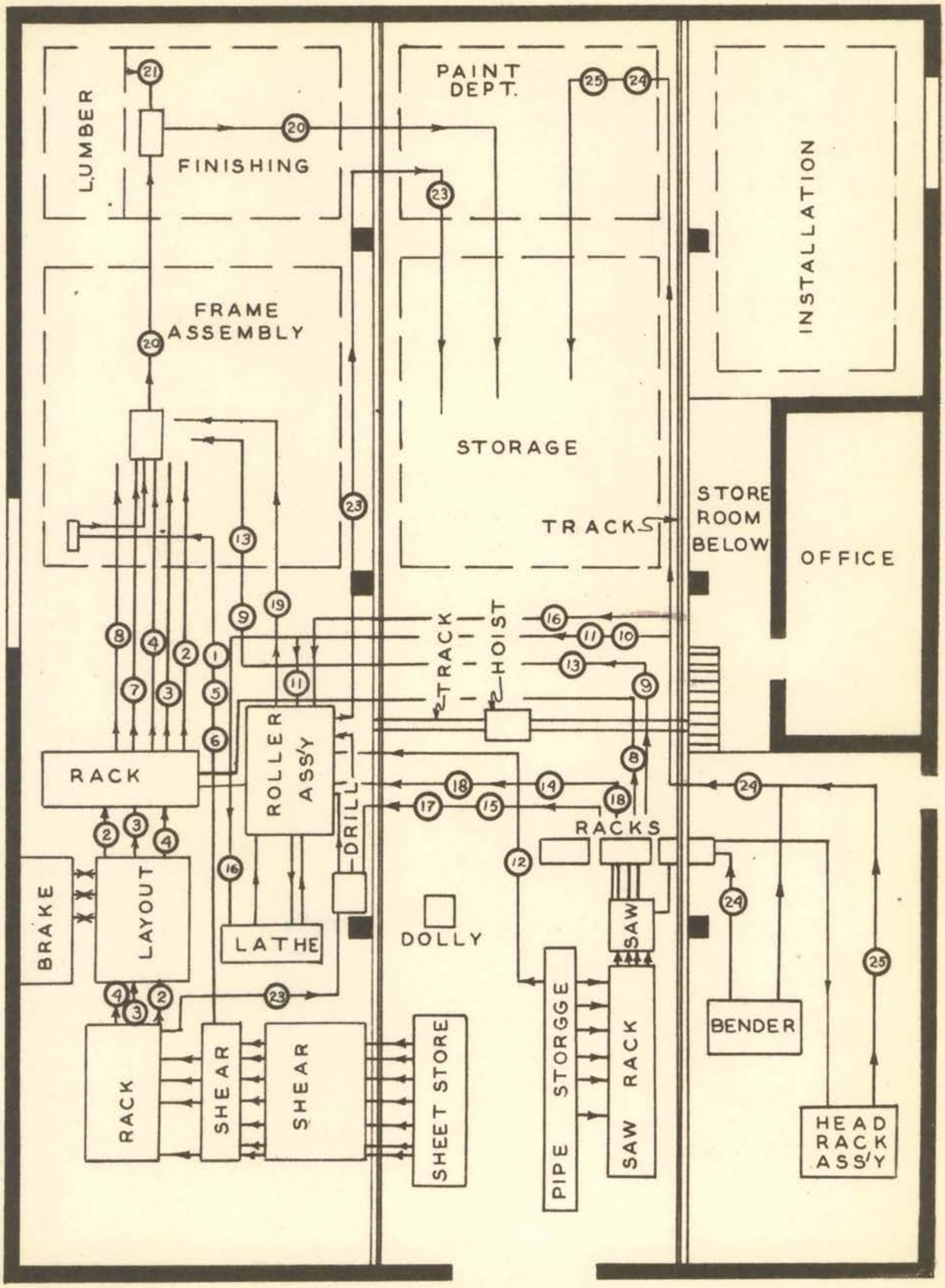


Figure 5-8

CONTINUOUS-FLOW FINISHING IN MULTISTORY BUILDING

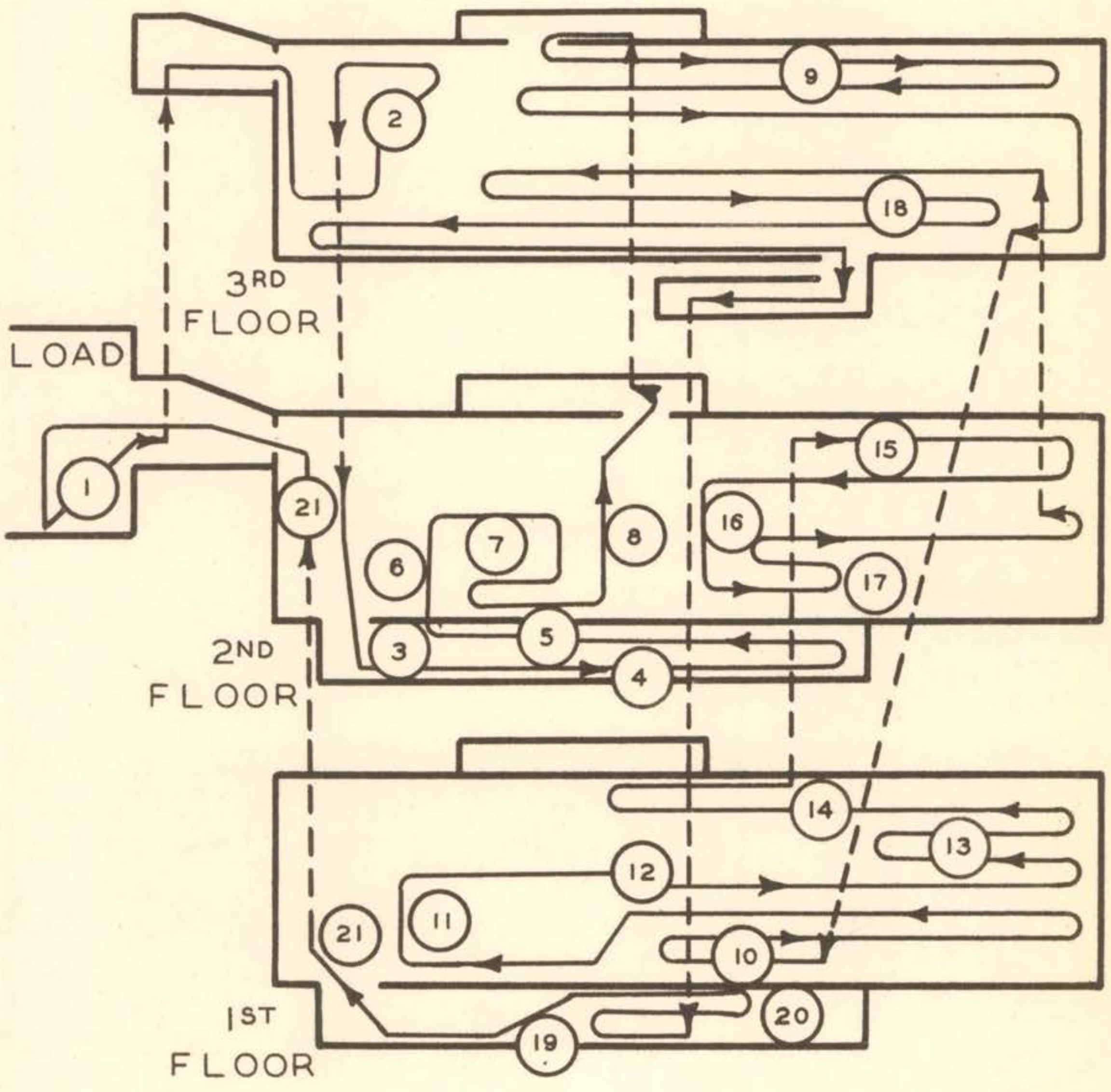


Figure 5-9

CHAPTER VI

EVALUATION AND SELECTION OF MATERIAL HANDLING EQUIPMENT

Ages ago inventive man began to transfer lifting and carrying to beasts of burden, to the pulley, and to the wheel. As the machine age accelerated output, the need for speedy movement of materials became greatly intensified. With the advent of mass production, there arose an imperative demand for even faster, more efficient ways to provide a steady flow of materials to and from machines. Today, American industry leads the world in mechanized materials handling efficiency; but the ultimate is still to be achieved.

Young as it is, American industry has advanced tremendously in machine efficiency, in tool development, and in production systems, particularly in the past generation. These production achievements have helped industry to increase its output per man-hour and up to now have made possible a steadily advancing living standard for our people. But, we must now attain even greater efficiency and at the same time prepare for the inevitable new challenge, competition in world markets against labor costs which, even though world living standards rise, will still be lower than our own. The next great reduction in American production costs can be effected by cutting material handling costs with the use of the most modern equipment and methods.

The modern plant is basically a materials handling system, for production is material in motion. Whether the ingredients or parts for the manufactures comes to the plant in bales, bags, barrels, bins, boxes, reels, drums, or cartons, all must be moved into stores, into production, and then, as finished products, into storage and into shipping.

Materials handling is an indispensable factor in any factory, warehouse or terminal operation. It begins with the raw material, continues on through processing and production to storage and even to the final delivery of the finished product to its destination. Only when it is realized that handling materials is an essential part of the operation, and that it consumes a major share of the time of that operation, can the importance be fully appreciated in relation to the profit-and-loss statement.

Materials handling is known to consume at least 30 percent of the total time required to produce manufactured goods.[1] It is the responsibility of management to find new ways to reduce costs; each step taken to reduce the number of handling operations helps toward that end. Because the means used to move goods determines, to a large degree, the cost of the finished product, it is highly important that proper consideration be given to how far, in what directions and how often the material must be moved, and the manpower time and equipment required to do the job. Only through a study of such factors as these is it possible to uncover inefficiencies and to apply corrective measures which will save manpower and time.

In general, all materials handling equipment makes use of two basic motions - horizontal, vertical, and a combination of both - to move materials into stores, in processing, and into storage and shipping. The horizontal motion, as accomplished through the application of the industrial truck, provides a transfer of materials from one point to another. While this is the most simple of the two basic motions, it is without question the most frequently seen in industry.

Few better opportunities present themselves for saving time and labor

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[1]L. P. Alford, Principles of Industrial Management, p. 102.

than are found in eliminating all possible manual vertical lifting. Lifting and lowering, as accomplished through the application of a hoist, has probably contributed more to industrial development than any other mechanical factor, for it quickly handles materials far too heavy for human strength. Pickup, carry, lift, and delivery constitute the combination motion. The term, as it applies to movement of materials, does not place close limits on the operational sphere of the performing equipment. In many industries the combination horizontal-vertical motion is all important because, with proper equipment, it provides the most economical handling to and from stores, through production, in shipping, and the most efficient use of existing storage facilities.

The approach to a solution of materials handling problems must of necessity be analytical. Just as F. M. Taylor studies man-motions in machine operations in his search for faster production, so the industrial executive must apply critical examination to all the complexities of handling materials in his plant. What must be moved, how far, and how often are vital factors to be considered, not only when more intensive use of existing equipment is sought but when planning for new equipment purchases to speed production flow.

Efficient materials handling equipment is both servant and master of production machines. It is a basic tool in warehousing, and in serving machines and common carriers - conserves manpower and time for jobs which result in greater output. By its ability to carry great quantities of material easily and quickly from where it is to where it is needed, efficient handling equipment prescribes the subdivision of complex operations into simple tasks and releases valuable labor for higher-paying employment. It helps in many ways to raise machine and man-hour productivity, to lower over-all unit costs, to reduce the plant floor space required for a given volume of parts or finished products, and to minimize safety hazards and the dangers and expense of worker fatigue. Probably no error in the application of materials handling machinery is more common than the calm assumption that one type of equipment is best for all jobs. Just as there are no all-purpose production machines, so there are no all-purpose handling machines.

Probably the most important step in solving the materials handling problem is to evaluate the available types of handling equipment and determine which is best suited to meet the particular requirements.[2]

Objectives of Material Handling[3]

1. Expedite intra-plant movement of parts.
2. Insure delivery to proper destination.
3. Synchronizing production aid.
4. Prevent accidental damage to parts in transit.
5. Maintain rate of production.
6. Avoid waiting time delays of machine operation.
7. Eliminate unnecessary movement of supplies.
8. Conserve floor space.
9. Minimum of manual assistance to move supplies.
10. Provide for automatic cleaning, cooling, and processing of parts.
11. Guard workers against strains and accidents.
12. Prevent excessive stock storage in production areas.
13. Avoid nonproductive employment of labor.
14. Expedite scheduling.
15. Lower unit cost of moving and handling materials.
16. Permit greater production per employee.

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[2]Material Handling Analysis Guide, p. 28.

[3]Economics of Tools and Equipment, p. 102.

17. Improve employee morale.

Types of Equipment Available

Conveyors

If a large and constant flow of relatively small units is to travel over the same route, a conveyor is probably the answer to the problem.[4]

From their meager beginnings, conveyor systems have spread to almost universal use throughout industry. However popular their use has become, they are very much limited as to capacity. Standard systems employing either gravity or power conveying equipment are limited to the handling of rather light loads. This does not means of feather proportions, but neither does it mean loads of much over a ton. Conveyors are flexible in their usages and are readily adaptable to any need. They may be installed as a permanent fixture of the plant or used in a portable nature wherever the need may arise. Each of the various types listed below is followed by a discussion of their individual capacities and advantages.[5]

1. Gravity Roller Conveyor - Designed to carry any commodity having one smooth firm traveling surface. While the exact grade of gravity operation varies with the size of roller and weight of commodity, an average drop of 3/8 inch per foot to 1/2 inch per foot is used.

2. Gravity Roller Spirals - Usually constructed with tapered rollers mounted in frames formed in the shape of a spiral. This provides a means of lowering packages from a higher elevation to a lower point within a relatively small area and is particularly adaptable to the handling of fragile packages.

3. Gravity Wheel Conveyor - For solid smooth bottom commodities, this conveyor operates at the same pitch as the roller conveyor. It is used extensively for portable work because of its light weight.

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[4] _Ibid._, p. 28.

[5] _Scientifically Planned Conveyors_, pp. 3-27.

4. Sheet Metal Slides - When a rapid descent is desired between two points and the difference in elevation is not too great, when it is necessary to have minimum floor openings these slides prove adaptable.

5. Spiral Chute - Lower cartons, cases, boxes, sacks, and similar commodities for any number of stories in a building. Runways range from 12 to 66 inches in width.

6. Belt Conveyor - For practically any commodity. These units designed for horizontal, inclined, and declined travel or a combination of all three. Permits handling of cased and packaged goods up inclines of 27 degrees.

7. Live Roller Conveyor - Any commodity which can be successfully handled on roller conveyor can also be carried on live roller conveyor.

8. Chain Conveyor - Single and multiple strands of chain are used for carrying cases, cans, and kegs in both straight and curved planes.

9. Slat Conveyor - Available with hardwood or steel slats will carry heavy and bulky material which cannot be handled on belt conveyors.

10. Bucket Conveyors - Primarily used for conditions where material is to be distributed some distance from the vertical lift.

11. Incline Elevator - This conveyor uses a pusher bar between two strands of chain which engage and push the commodity on a steel slide up an incline as desired. Standard units are made in 30, 45, and 60-degree inclines.

12. Straight Lift - Comparable to incline in construction but designed for straight vertical lift and lowering.

13. Piling Machine - Sacks and boxes may be piled from a few feet to 30 feet by this equipment.

14. Lower Lift - Elevates and lowers trays for any number of stories. Trays may be of cafeteria style or tote box type for industrial purposes. A variation of this type is the Record Lift, adaptable for carrying documents for any number of stories. This machine is used in insurance companies and hospitals for transmission of papers between floors.

Other types of conveyors may be produced on special order. Various adaptations of these mentioned may be found, but in general all in use will fall into one of the described classes.

Cranes or Hoists

The hoist was probably one of the first handling devices put to use. Unquestionably it has helped industry solve production problems which could not have been overcome without it. Many hoists are operated manually, but the motorized type meets the need for equipment which speeds work and replaces human energy with electric power.

Hoists are commonly used to handle sub-assemblies on production lines, to center work over machines, to assemble and dismantle or move large plant equipment, to transfer materials from one floor to another, and to lift and transport parts from stores to processing and between processes, from storage to common carriers, in repair and construction work, etc. In fact, the broad and varied application possibilities emphasize the tremendous importance of hoisting equipment not only for vertical lifting but for moving materials horizontally on an overhead trolley track, with or without diverting switches, or on a jib crane.

A disadvantage in the use of cranes within buildings is the amount of overhead space necessary for their operation. This space can be used for storage if some other type of materials handling equipment will do the work efficiently.

Because modern manufacturing processes are so complex, the need is great for planning and adapting hoisting equipment to fit the requirements of a given plant or use. So infinite are the conditions under which the hoist must work that careful consideration should be given to frequency of use, load, length of lift or horizontal travel, manual labor, efficiency, headroom, safety, and economy. Only through evaluation of such pertinent factors is it possible to determine what type will best suit a particular situation.

Trucks, Tractors, and Trailers

Hand lift trucks are of two basic types, pallet and platform. The former requires a pallet with openings in the bottom deck which permit the rear wheels to operate; the latter a skid. Used within departments and for short hauls, these trucks simplify routing and placement of storage or production items and speed their movements. Direct handling economies often run as high as 200 percent on the investment, with this type of equipment. In addition to eliminating rehandling, the motorized hand-lift truck has many other advantages over the push truck and the dolly, such as: (1) greater load carrying capacity saves time; (2) self-loading conserves manpower - one man can lift, transport, and deliver multi-unit loads; (3) the safety factor is greater due to load stability and minimum dependence on human strength; (4) worker fatigue is reduced; and (5) less handling controls damage.

The development of self-loading power trucks laid the basis for what are the most distinctive and important advantages of today's handling system. The self-loading low-lift platform truck, provides safe horizontal transportation of weights up to 60,000 pounds, loads and unloads without straining a muscle, travels fast, and maneuvers easily in congested quarters. Used with skids or skid bins, the low-lift platform truck moves extremely heavy loads quickly within a wide operational area and conserves human energy and man-hours while stepping up production volume.

The particular usefulness of the electric trailer train is in fast long hauls or great quantities of goods from storage to processing, warehouse to warehouse, or to loading docks. Although only a tractor driver is required, as in all other haulage systems, external loading and unloading facilities must be employed.

Manufactuerers, railroads, utilities, and other basic industries use the crane truck because of its economy, unlimited operational range, versatility, spotting accuracy, and great load carrying capacity. In some plants it replaces the overhead traveling crane to permit the construction of a balcony work area, thus relieving congestion and increasing production without adding to land requirements.

The development of itinerant materials handling equipment probably did more to hasten the conversion of straight line production to the more efficient departmental system of group machines than any other single factor. For where a number of related production sequences are carried on, the application of this type of equipment becomes imperative. Electric industrial trucks quickly deliver materials to and from zone storage with maximum economy of manpower and time, while hand-lift trucks feed parts to machines from zone storage and to other machines, thus reducing waiting time and increasing hourly production.

The biggest share of storage costs often lies in the methods used to move goods in and out of warehouses, terminals, and common carriers. Whether products are in bags or are machine parts of odd shapes, practically anything can be put on pallets in quantity and handled with great savings in time, effort, and storage space. Large heavy pallet loads can be picked up, carried, and tiered to the ceiling in a few minutes by one man with a high fork lift truck, instead of many men straining over push trucks for hours, lifting, loading, and stacking. In recent years, management has done much to minimize the rehandling factor in distribution costs, but pallets can be used profitably in many plants that have not yet adopted them.

When there is a flow of materials moving a long distance (over 150 feet) from a central point to a number of destinations, it will probably be found that a tractor-trailer operation will furnish the most economical answer to the problem.

If there is a regular or intermittent flow of materials, or both, over a number of routes and areas, the solution to the materials handling problem will be found in lift trucks. The maneuverability and versatility of the lift truck offers a practical and economical solution to most types of handling problems. It is capable of performing a variety of loading, unloading, stacking, moving and storage assignments.

The lift feature alone makes it possible to use overhead space for storage, even in confined areas. Lift trucks are also used for handling bulky, odd-shaped materials by employing one or more special accessories, such as scoops, crane arms, rams, etc., which can be substituted for the standard fork equipment.

Because it combines features of all other materials handling systems, the lift truck will be found adaptable to almost any problem, especially those not easily solved by the use of conveyors, cranes or tractor-trailer combinations.

Cost Comparisons

There is no intent to create the impression that any one system is a "cure-all" for every material handling problem. Each system has its advantages, if properly applied. The following illustrations and graphs provide a means for determining the most economical system on a cost per ton basis.

The relative costs of transporting materials by fork truck and by fork truck-tractor trailer combination is shown in Figure 6-1.[6] The fork truck provides the lowest cost per ton is short and medium length hauls. For longer hauls it is cheaper to place the load on a string of trailers which are taken to destination. In stevedoring operations the loads are lifted from the trailers by the ship's tackle. In other applications a second fork truck may

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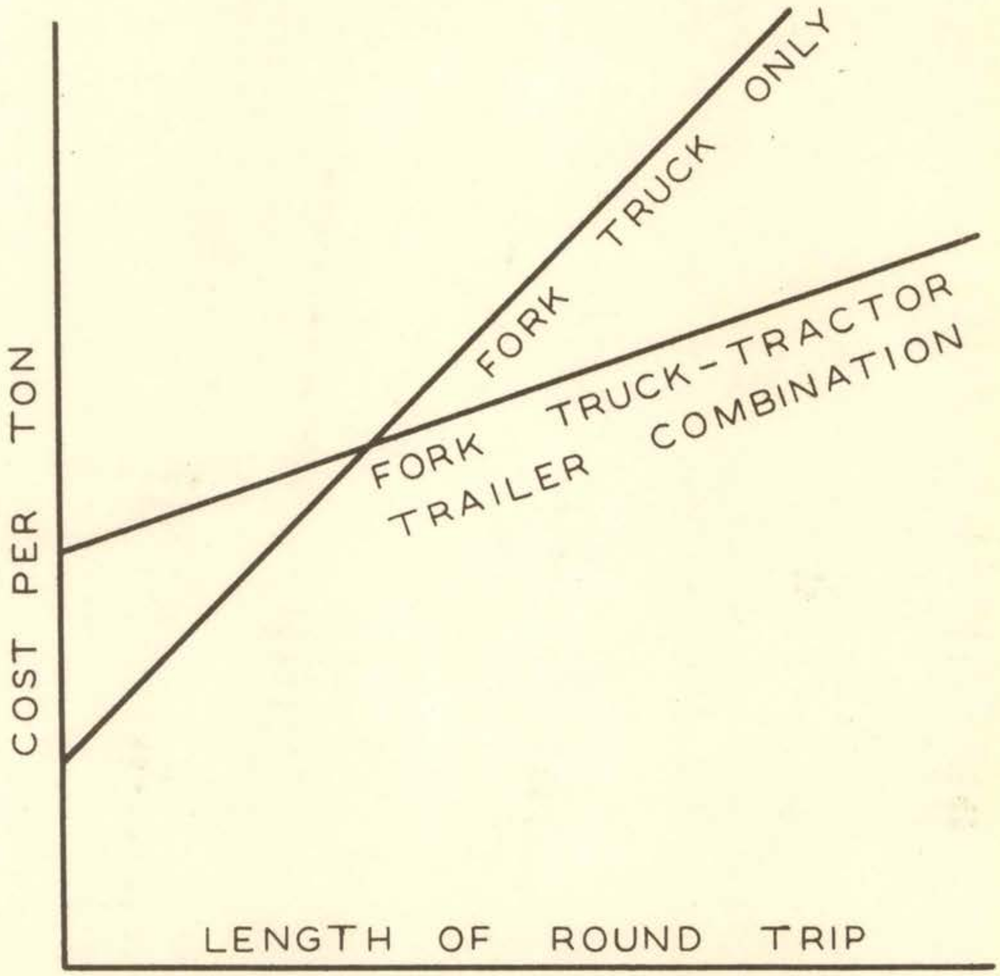
[6] Unit Loads, Their Handling - Shipment - Storage, p. 12.



RELATIVE COST OF TRANSPORTING MATERIAL BY FORK TRUCK AND BY FORK TRUCK-TRACTOR TRAILER COMBINATION.

Figure 6-1

be needed to complete the operation.

The Low Lift Truck shows the lowest cost per ton because it combines the self-loading feature with a low first cost and low operating cost. Although its first cost is still lower, the non-elevating platform truck shows a higher cost per ton because it must be hand loaded and unloaded. Figure 6-2 shows the relative cost of transporting materials by different types of power trucks, no tiering being required.[7]

The fork truck offers the lowest cost means of tiering materials because it eliminates all manual operations. In Figure 6-3 the relative cost of hand piling is compared with stacking by fork truck.[8] With hand piling the cost increases rather rapidly as the piling height is increased but this is not true of the power fork truck.

These charts, it is felt, clearly indicate that no one system should be first choice under all conditions but rather show that combination of the various systems will yield maximum results.

A power truck can make such huge savings in comparison with the cost of manual handling, that it need not be busy continuously to show a profit. In many instances, a truck having no more than an hour's work a day can pay for itself inside of a year. Determination of the volume of work at which power handling begins to pay is, therefore, one of the very worthwhile, practical uses of operating-cost estimates.

As an illustration, the advisability of purchasing a 2-ton tow-lift elevating-platform truck will serve. Assume that the work for which it is to be used is the movement of material over a distance of 100 feet. If the mater-

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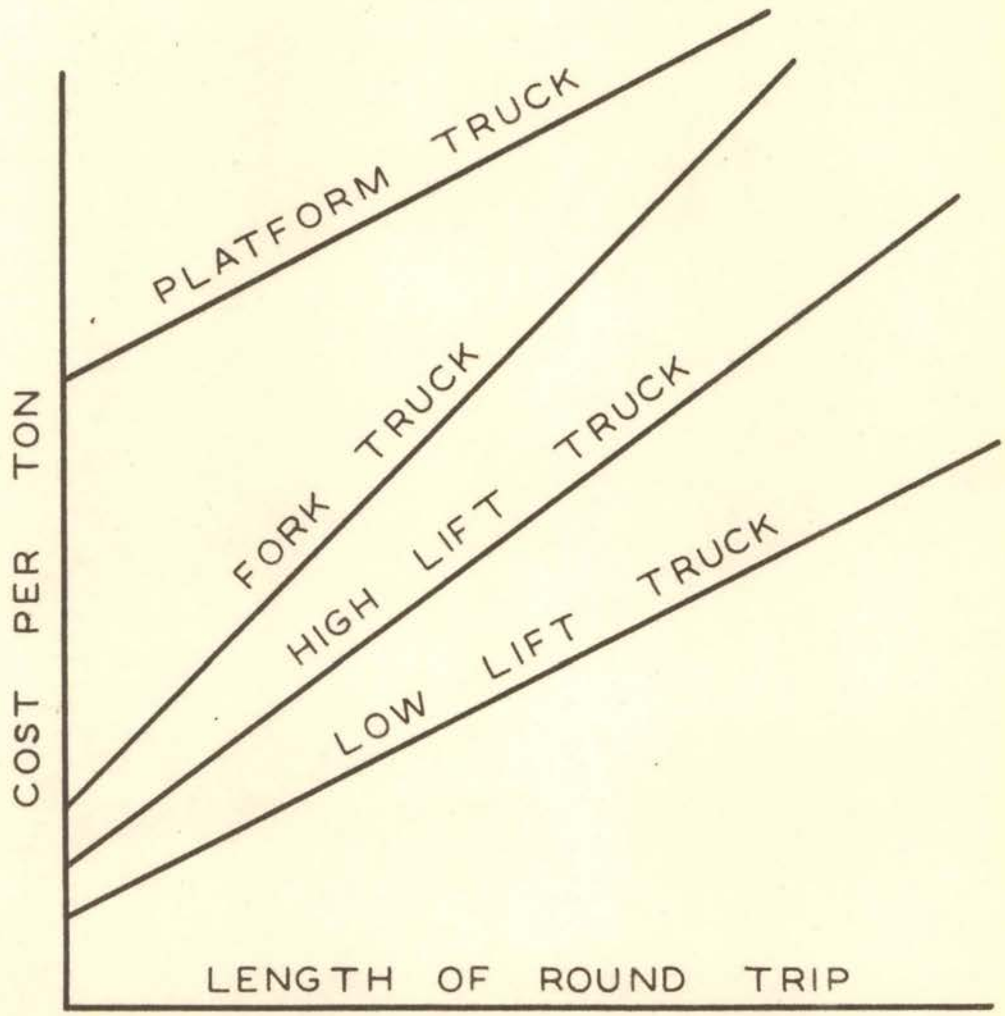
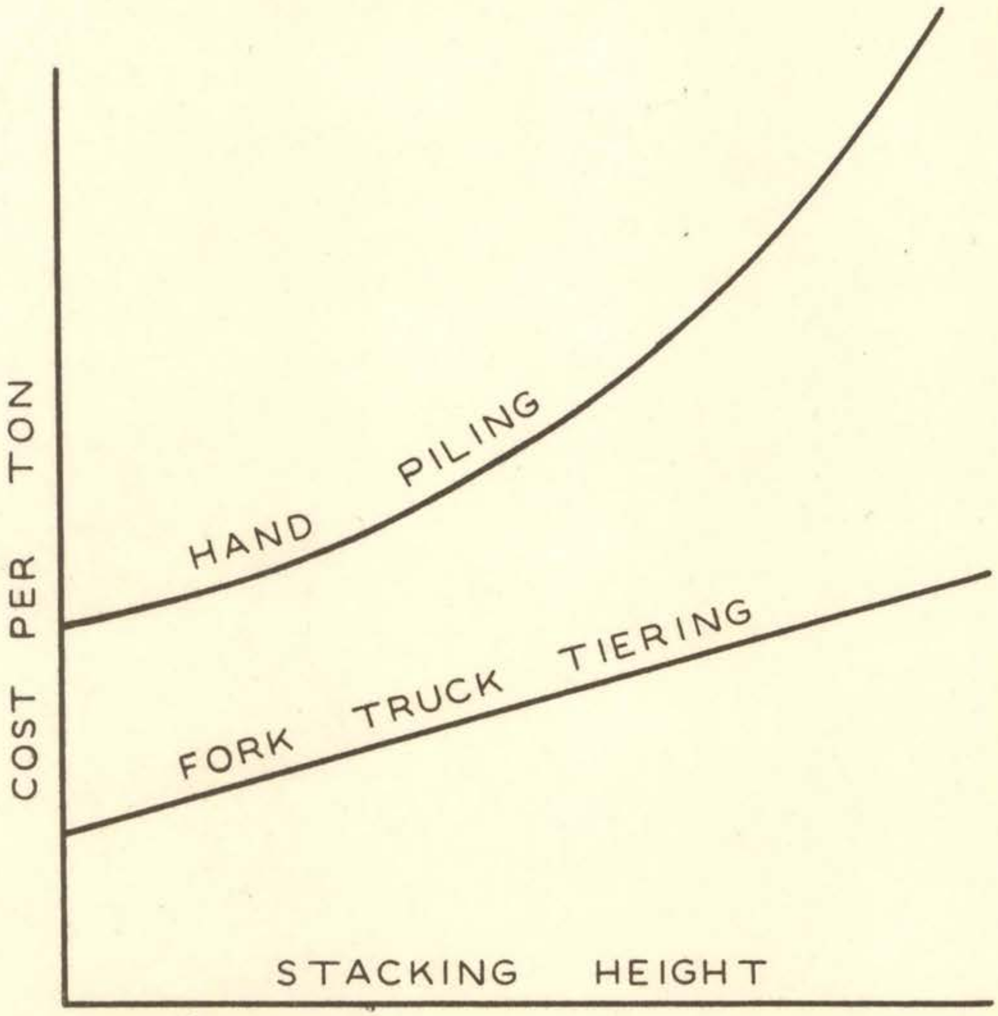
[7] Ibid., p. 12.

[8] Ibid., p. 13.



RELATIVE COST OF TRANSPORTING MATERIAL (NO TIERING) BY DIFFERENT TYPES OF POWER TRUCKS.

Figure 6-2



COMPARISON OF RELATIVE COSTS OF HAND PILING WITH STACKING BY FORK TRUCK.

Figure 6-3

is piled on skid platforms of 2 tons each, the truck, working continuously, might be expected to handle 53 loads (106 tons) per hour. Its required battery capacity for 8 hours was estimated to be approximately 8.2 kwhr., the capacity actually used per 8 hours, approximately 6.6 kwhr.

Under method No. 1, the material is being moved by hand truckers who handle an average of 350 pounds per trip and make an average of 20 trips per hour.

To find the volume of this work above which the purchase of the truck will show a profit, it is necessary to estimate the cost per ton by the two methods.

A typical estimate of the cost of operating the truck 8 hours a day would be approximately as follows:[9]

1.	Net price of truck	$2,000	
2.	Cost of one set of tires	100	
3.	Depreciation basis	1,900	
4.	Depreciation: 6 1/2% of Item 3		$ 123.50
5.	Annual tire cost		100.00
6.	Net price of battery	450	
7.	Depreciation: 16 1/2% of Item 6		74.25
8.	Net price of charging equipment	600	
9.	Depreciation: 5% of Item 8		30.00
10.	Maintenance of truck		80.00
11.	Maintenance of battery		30.00
12.	Maintenance of charging equipment		10.00
13.	Charging current		40.00
14.	Insurance		10.00
	Total per year		$ 497.75
	Total per 8-hour day (basis, 260 days per year)		1.91

Assuming, in order to be conservative, that the cost per day will remain at $1.91 even though the truck works less than 8 hours and that the operator's wages are $1.00 per hour, we have the following:[10]

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[9] Material-Handling Handbook, pp. 48-49.

[10] Ibid., pp.48-49

Hours per Day	Total Trips Made	Tons Han-dled	Cost of Truck	Cost of Wages	Total Daily Cost	Cost per 100 ton-ft.
1/8	6	12	$1.91	$ .13	$2.04	17.00 c.
1/4	13	26	1.91	.25	2.16	8.30 c.
1/2	26	52	1.91	.50	2.41	4.65 c.
1	53	106	1.91	1.00	2.91	2.75 c.
2	106	212	1.91	2.00	3.91	1.84 c.
4	212	424	1.91	4.00	5.91	1.40 c.
8	424	848	1.91	8.00	9.91	1.17 c.

The hand-trucking cost will depend very largely on truckers' wages. If wages are 50¢ per hour, the cost on the basis of 3 1/2 tons per trucker-hour, will be 14.3¢ per ton. If, therfore, there is enough work to keep the truck busy 1/4 hour a day, it will begin to show a profit.

The price of the truck has been assumed to be $2,000, the price of the battery $450, and the price of the charging equipment $600, making a total investment of $3,050. The amount earned on this investment may be estimated as follows:[11]

Hours per Day	Tons Han-dled	Power Trucking Costs	Hand Trucking Cost	Saving Per Day	Saving Per Year	Per Cent Return
1/4	26	$2.16	$ 3.72	$ 1.56	$ 406	13
1/2	52	2.41	7.45	5.04	1,310	43
1	106	2.91	15.16	12.25	3,180	104
2	212	3.91	30.32	26.41	6,870	225
4	424	5.91	60.64	54.73	14,230	466
8	848	9.91	121.38	111.47	28,951	949

Thus, under the conditions assumed, the truck would pay for itself within a year if kept busy one hour a day, and in about a month and a half if kept busy all day. There are recorded instances in which even this maximum return has been exceeded.

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[11] Ibid., pp. 48-49.

One reason is that, as a practical matter, hand trucking costs do not remain the same regardless of volume. Experience has shown that an aisle-way used for hand trucking, always has a volume limit above which congestion occurs, slowing down the movement and raising the cost. Depending upon the width of the aisle, the assumed hand-trucking costs, as shown in the foregoing table, would probably be exceeded long before the volume had reached 848 tons per day.

However, the most important fact demonstrated by such cost analyses is that a truck need not be busy all day in order to earn a direct profit.

In organizing an industrial-truck handling system it is necessary to determine the best size of unit load for the commodity to be handled. This will indicate the required size or load-carrying capacity of the trucks to be used, while the length and number of trips per day, plus an allowance for maneuvering and other delays, will indicate the required number.

As an example, assume that 1,200 two-ton loads mounted on skid platforms are to be moved 100 feet in one eight-hour shift. From a manufacturers' specifications a 2-ton low-lift elevating-platform truck could be selected for which speeds would be given as 400 fpm loaded and 500 fpm light; time to pick up load, 4 seconds; time to release load, 3 second.[12]

On the basis of these specifications, the time for one round trip would theoretically be:

	Seconds
Pick up load	4
Carry load 100 feet	15
Release load	3
Return light 100 feet	12
Total	34

[12] Ibid, p. 42.

As a practical matter, allowances must be made for acceleration, turning around, maneuvering into position to pick up or release loads, and unforeseen delays, which collectively may be termed the delay factor.

Ordinarily the delay factor is greater for short trips and smaller for long trips. It also varies as a result of other factors such as the skill of the operator and the number of different routes on which one truck may be used. Typical values for lift-and fork-trucks are:

Length of Route (ft.)	Delay Factor (Ratio of Elapsed to Running Time)
50	2.5
100	2.0
250	1.5
500	1.2

If a delay factor of 2.0 is applied to this example, the time per round trip would be increased from the theoretical value of 34 seconds to 68 seconds. On this basis, one truck may be expected to make 53 trips per hour and 424 trips per 8-hour shift. To handle 1,200 loads, three trucks would be needed.

Final Analysis

When the material handling problem appears to be properly solved, use the check lists as follows to make certain all points have been given proper consideration.[13]

Production Check List

1. Are supplies transferred from operation to operation without manual handling?

2. Are they placed directly in the machine?

3. If they must be hand fed, are they placed so that the machine operator makes no unnecessary motions?

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[13] *Ibid.*, p. 6.

4. Are supplies always delivered at the speed they are used?

5. Is set-up time at minimum? Are tools changed as rapidly as possible? Are supplies delivered in units large enough to get the longest possible runs per set-up?

6. Is the plant laid out primarily for "straight-line" production or for process efficiency? If the latter is preferable, would more flexible handling methods permit its installations?

7. Has manual handling been eliminated where ever possible?

8. Is scrap disposed of without manual handling?

Receiving and Storage Check List

1. Are incoming supplies (other than bulk commodities) received in unit packages suitable for power handling?

2. Are they unloaded and delivered without manual handling?

3. Are they stored to the roof whenever possible, without manual handling?

Packing and Shipping Check List

1. Are completed products packed in unit loads suitable for power handling?

2. Are they stored to the roof where possible, without manual handling?

3. Are they stowed in outgoing carriers without manual handling?

Costs Check List

1. How many employees are engaged in handling supplies full time? Part time?

2. Is any skilled employee ever required to do ordinary handling work?

3. What proportion of the direct labor pay roll is represented by handling?

4. What is the cost per ton-foot of handling supplies between departments? Within each department?

5. What is the cost of defective supplies and spoiled work? What proportion from present handling methods?

6. What is the cost of lost time? What proportion from present handling methods?

7. What are the present compensation rates and to what extent can they be reduced by the reduction of handling injuries?

8. What proportion of lost-time accidents are a result of manual handling?

Handling Systems Check List

1. If handling has been mechanized, are the systems in use best adapted for the work?

2. Have they been supplemented by all improved auxiliary equipment capable of effecting further net gains?

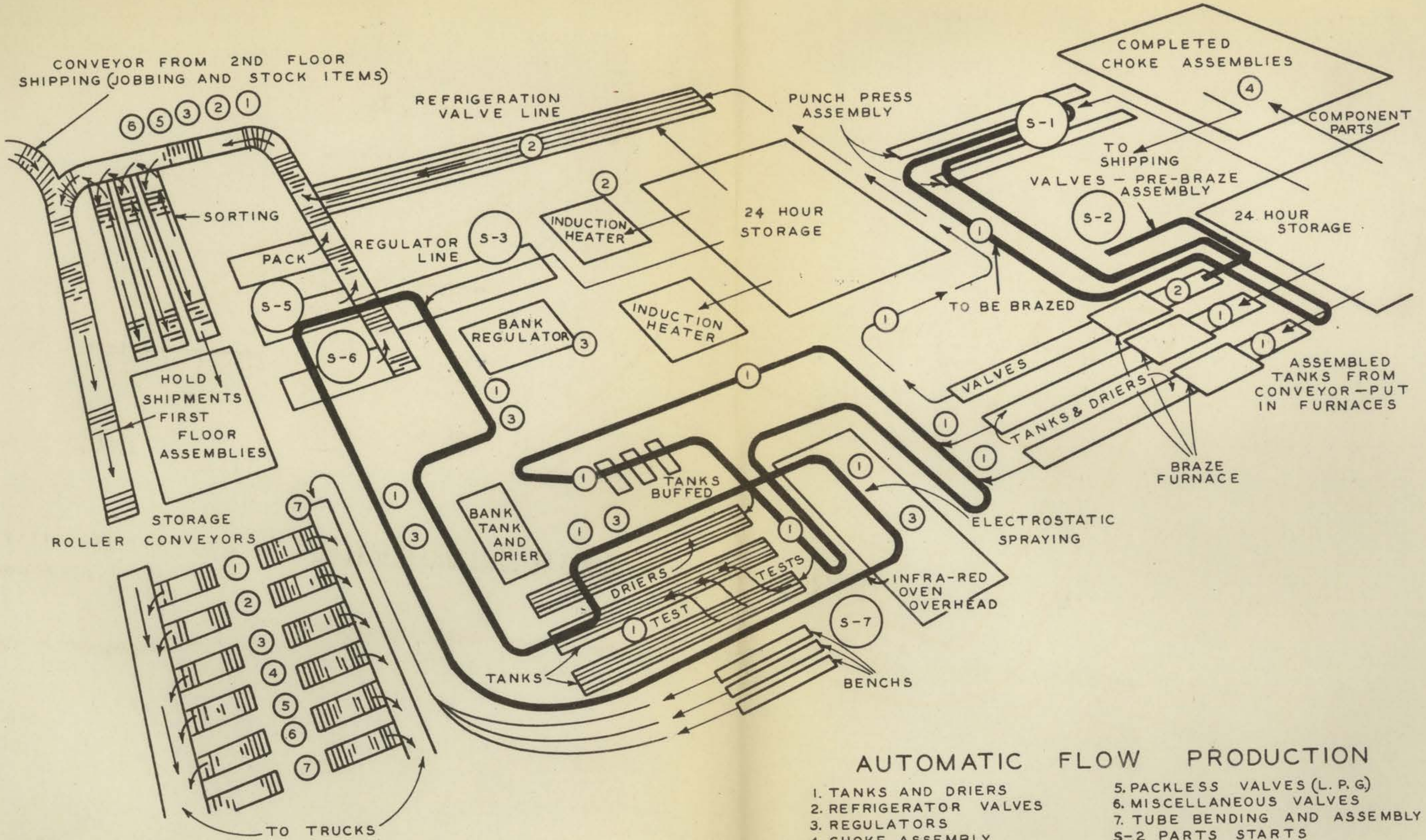
3. Has everything possible been done to assist suppliers to ship in unit packages suitable for power handling?

Figure 6-4 shows the planning of transportation facilities for small assemblies.[14]

The machines for primary operations, punch presses, spot welders, and so forth, are arranged in straight line flow. The machines are laid out in a double row with an overhead conveyor line between them. This conveyor is equipped with special carriers and is used to transport the assembled tanks and driers to the brazing room. It also serves as an overhead storage for the tanks which are bulky and difficult to store.

On the loading end of the furnace chain belt, an operator removes the tanks from the overhead conveyor as it passes within easy reach. On completion of brazing, an opertor removes the tanks from the furnace and hangs them on another conveyor which transports them to the buffing operation. Following buffing they are again transported to the testing line where they are placed on one of three trough belt conveyors. After the valve parts are assembled and the stem is tightened on the seat, the tanks flow to test booths. As the test operator needs tanks he causes the conveyor to move by a control button located in his booth. After testing, the tanks are placed on a second trough conveyor for the

[14]"New Layout for Small Assemblies Returns First Cost in Six Months," Factory Management and Maintenance, C (July, 1948), 100-101.



AUTOMATIC FLOW PRODUCTION

1. TANKS AND DRIERS
2. REFRIGERATOR VALVES
3. REGULATORS
4. CHOKE ASSEMBLY
5. PACKLESS VALVES (L. P. G.)
6. MISCELLANEOUS VALVES
7. TUBE BENDING AND ASSEMBLY

S-2 PARTS STARTS

OVERHEAD CONVEYOR

BELT CONVEYOR

ROLLER CONVEYOR

HANDTRUCK

Figure 6-4

remaining assembly operations.

The assembly floor was arranged to keep transportation of parts to a minimum and to arrange the different lines for proper space utilization.

CHAPTER VII

STORAGE, WAREHOUSING AND STORESKEEPING

The department of stores is charged with the responsibility of physical possession of the materials in the plant. Stores may be held in a central storesroom or in departmental storesrooms, either under control of departmental stores organizations or of central stores or material control organization. The latter is preferable, for the reason that it entails a smaller organization and less clerical labor, and also tends to reduce inventories by being able to transfer surplus stock from one storesroom to replenish depleted stock in another.

Even where an organization operates plants in different localities, a central material control is usually desirable. In such cases each plant maintains its own detailed records and balance-of-stores ledgers, but a master control should be kept by the central organization, to which variations in the stores of the individual plants should be reported at regular intervals, daily, weekly, or monthly as may seem most desirable.

Intelligent planning ahead of production can avoid hours of labor and dollars of expense. The best results and a minimum waste of space and operating expense will result from observing the following sequence in planning new storage areas:[1]

1. Plan structures so that entrances, aisles, posts, platforms, windows and other necessary features will not interfere with, but will facilitate, the most desirable layout of the stores themselves.

2. Determine proper layout of storage and aisle space, with general location of items, and calculate total space needed.

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[1] L. P. Alford, Cost and Production Handbook, p. 488.

3. Determine proper unit storage space.

4. Determine proper aisle spaces.

5. List and classify all items according to:

    a. Measurements.

    b. Difficulty of handling.

    c. Frequency of use.

    d. Special considerations, as of sensitiveness, perishability, or of peculiar similarity.

    e. Quantities to be carried.

An important feature of inventory control is classification and its expression by means of symbols. It should be reduced to a unified system. This necessitates a careful grouping of all activities. The system of classification should follow fundamentally the order of accounts shown in the general ledger. The main groups usually encountered are as follows:[2] (1) raw materials; (2) work in process; (3) manufactured parts; (4) parts purchased - finished; (5) finished products; and (6) supplies and perishable tools.

Within groups, the plan of classification must be determined upon a logical basis. All items being grouped under their proper classification, each item should receive a distinctive symbol and description, and each should have a distinctive place in its own group.

The storage arrangements are affected by the character of the materials to be stored. Material that is not affected by weather can be stored out of doors, or at best under an open shed, or merely protected by a roof to prevent its becoming buried in snow, sleet, or ice. Sand, lumber, unmachined iron castings fall in this category. Materials such as plaster, cement, must not only be protected from the weather, but must be stored in places that are dry.

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[2] Ibid., p. 488.

Materials that are subject to corrosion such as machines, castings, and forgings, must not only be stored in dry places, but in certain instances must be slushed to prevent rust. Liquids or materials whose character is changed by low temperatures must be stored in heated storesrooms. Dustproof bins must be used for storage of such items as finished textile goods and other materials which may be damaged by dirt.

The problem of allocating space in a storage area is simplified by selecting certain products as yardsticks and to convert the storage space requirements of all other products into the equivalent of those products. This yardstick is known as the standard unit storage area and is the basis for the entire layout. To avoid confusion in the indexing, rows of such size as to require the splitting of the standard unit should be avoided. For instance, if a unit is 3 feet long, a row may be 12 feet or 15 feet long but should not be 10 feet or 14 feet long. Bins are frequently smaller than the standard unit, and space for them must be planned accordingly. If the rectangular unit is not square, it is wise in planning for floor or platform areas to have the short dimensions of the unit parallel the length of the row and the long dimension is its depth; for instance, if the unit is 4 x 3 feet, a row of five such units would be 4 feet wide and 15 feet long - the units adjoining each other on their longest side. A double row of 10 units would be two single rows side by side, giving a storage area 8 feet wide and 15 feet long.

When planning layout for bins, it will frequently be possible to have the outside depth of the bin just half the depth of the unit area; for instance, if the unit area were 38 x 38 inches, one unit area would hold 2 bins, back to back, resting on the 38 x 19 inch side. A single row of unit areas would thus serve without loss of space, for a double row of bins opening on the 38 x 19 inch side. A floor or platform layout for bulk or case goods, planned with such a unit, would provide for a double row of units which would make the maximum storage space 76 inches deep.[3] (See Figure 7-1)

Whether platforms or bins are used, sub-aisles on each side of every double row give the necessary direct accessibility to every storage space. In general, a layout planned with the standard unit areas is flexible, affording the desirable possibility of using the same space at different times to adapt the layout for different purposes, without upsetting the existing plan.

In oblong sections, crosswise rows are preferable to lengthwise rows. (See Figure 7-2). If a section is approximately square, the rows should generally be at right angles to the direction of greatest traffic.[4] Parallel rows only should be in any given section. Rows of different directions, as at right angles to each other or lining all four walls, should be avoided.[5] (See Figure 7-3). Any necessary change in the direction of rows should properly determine a new section as it is difficult to number consistently the rows in a single section if they run in different directions. The common tendency to line all four walls or boundaries with storage spaces is to be avoided. If such a condition is found ready-made, it should be treated as an exception and remedied at the first opportunity. This is not always easy where shelves or racks are built in and is another argument in favor of interchangeable unit bins. If the initial rows run east and west, all the rows in that section should be parallel to them not only for ease in numbering, but also for economy of space.

Straight lines and right turns should be used for aisles and rows. Economy of space is increased by uniformity of plan. Aisles are to be governed by necessities of use in determining the width, location and arrangement.

The bulk of the material and the size of the conveyors are determining

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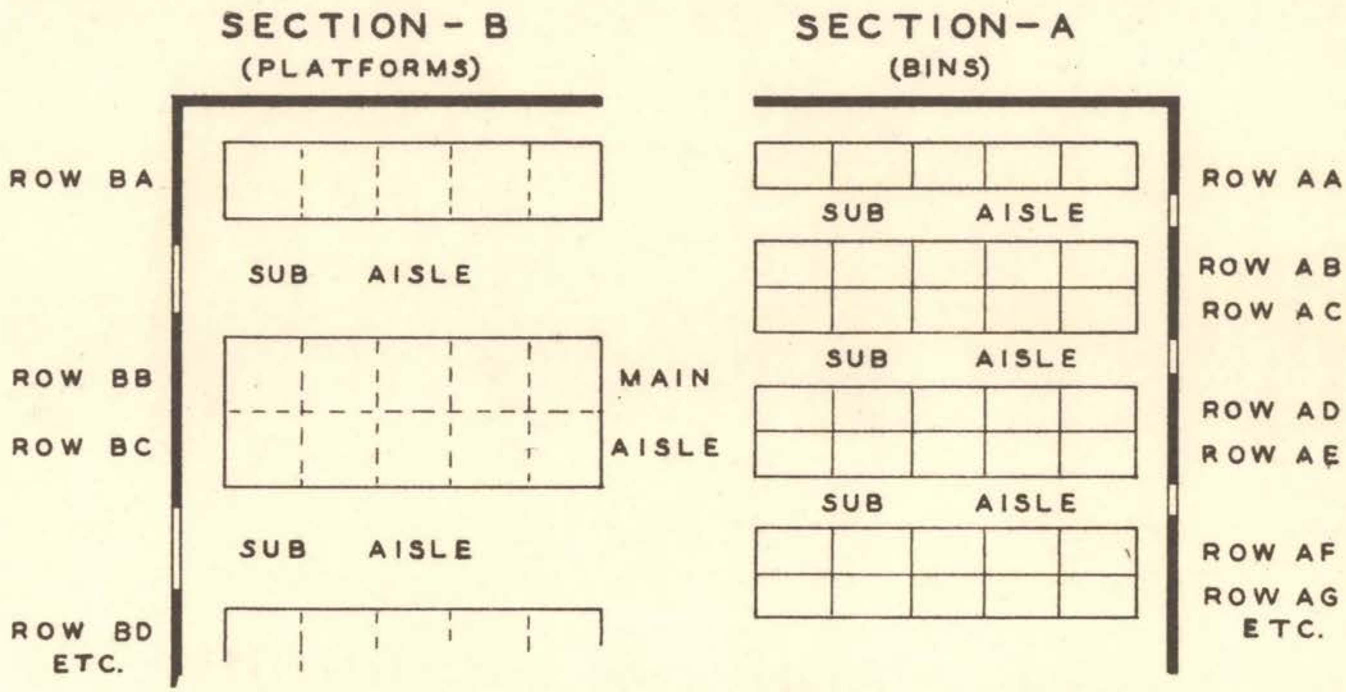
[3] Ibid., p. 492.

[4] Ibid., p. 492.

[5] Ibid., p. 493-494.



SEPARATE SECTIONS IN ONE ROOM DUE TO LACK OF UNIFORMITY OF ROWS

Figure 7-1

factors for the proper width of aisles. Main aisles should be wide enough only for the work to be done in them, such as for a given truck to turn around. Main aisles for two-way passage of trucks may need to be 6 or 8 feet wide or even more, according to conditions. Side aisles, connection aisles, or those straight through the building, need be but little wider than the truck aisles. Where goods are to be carried by hand, aisles may be made thirty inches wide. Aisles should not be so wide as to allow parking space for trucks.

Walls furnish natural supports for material and natural boundaries for sections. Floor space along a wall should not be used for an aisle if it can be planned for storage. An aisle along the wall can serve directly only one row of storage space across from the wall. If every aisle serves a row on either side, the proportion of aisle to storage space can be kept at a minimum.[6] (See Figure 7-4)

Haphazard marking of location is to be avoided. The marking system should be built up so logically that the process of locating any one item will be consistent with that of locating any other. Standard base lines or points of reference from which to begin any series of location symbols should be reasonably permanent. The boundary lines of all divisions of storage space should be clearly marked.

The symbol should be short, easily understood and remembered, and in itself a guide to the location designated. Without some system of symbols representing the complete description, systematic marking is impossible. A simple scheme of designation, brief, and showing the relation of any particular location to the whole has the requisites for effective handling of the problem. Sections and rows can often be indicated by painting symbols on girders, crossbeams, or posts.

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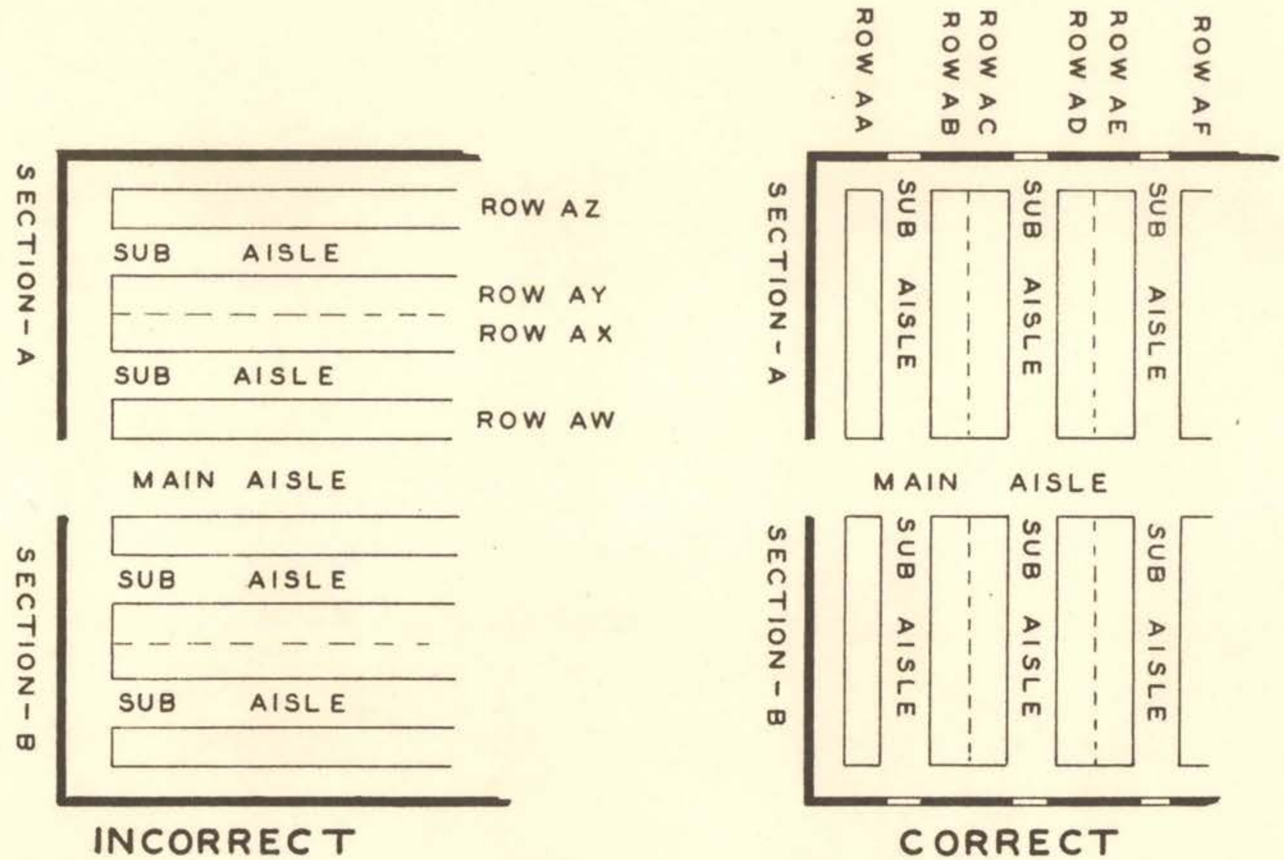
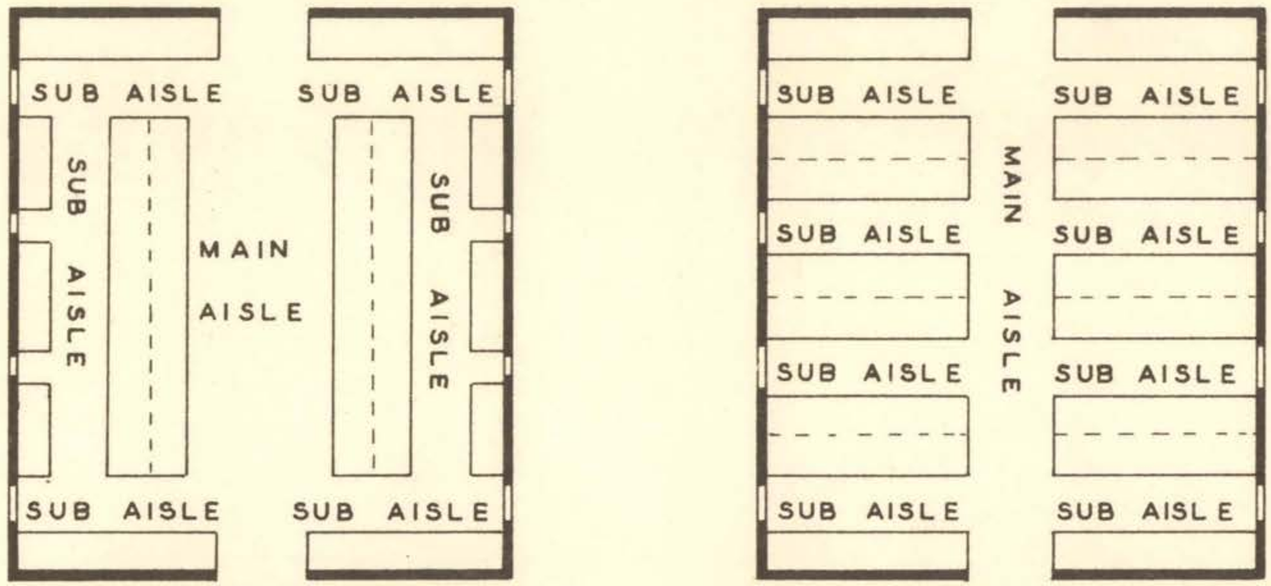
[6]*Ibid.*, p. 496.



ARRANGEMENT OF ROWS

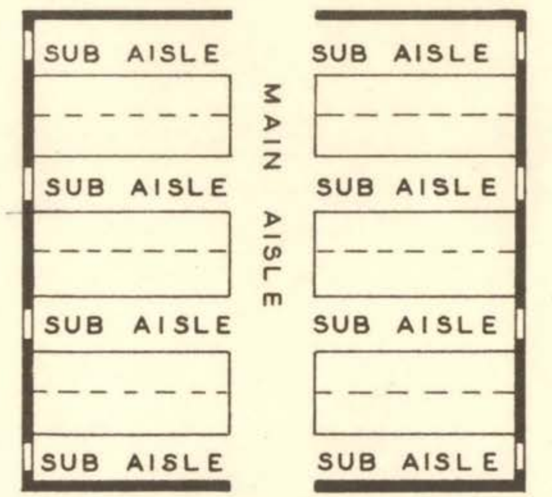
Figure 7-2



INCORRECT LAYOUT
FOUR WALLS LINED
WITH STORAGE SPACE

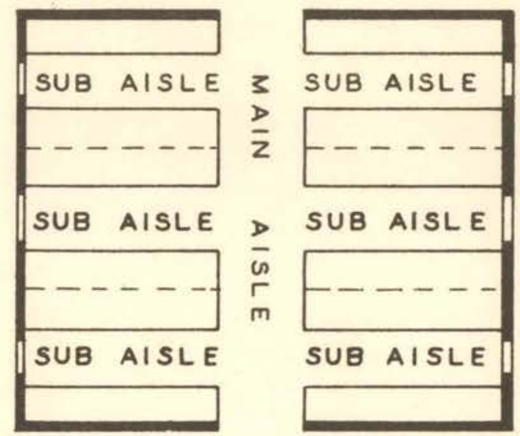
CORRECT LAYOUT
PARALLEL ROWS

Figure 7-3



INCORRECT LAYOUT

SIX ROWS WITH FOUR NARROW SUB-AISLE



CORRECT LAYOUT

SIX ROWS WITH THREE WIDE SUB-AISLE

Figure 7-4

Location symbolizing should be done in such a way that in case of expansion the existing symbols will be subject to the least change. If possible, additions to a given layout should make normal and convenient additions to the existing marking scheme and not require the re-marking of all or part of the layout.

The stores layout is divided into spaces definitely graded according to size, for the definite location of every item of stores. Any particular bin may have subdivisions which, however, will not be given special designation. The graded spaces larger than the unit are, in order of size, the section, row, series, and building or field, as the case may be.

Probably direction of future expansion is the most important factor in determining from which point or boundary the lettering of any one set or group of spaces should begin.[7] (See Figure 7-5). Natural bounds such as walls, aisles, roads, embankments, or streams and the like, will play a part in determining such expansion. By having the lettering run from A toward Z when lettering from north or east, and reversewise from Z toward A when lettering from the south or west, a general consistency of direction in all the lettering will be preserved.

Buildings, if lined up uniformly, should be lettered consecutively; if scattered irregularly, they may be lettered arbitrarily. In the case of standard warehouses, with movable partitions across the entire building, the position of the movable partition depends on the relative amount of material to be handled at either end. If any row or other division is incomplete, allowance should be made in the lettering so as to preserve uniformity with complete rows.

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[7]Ibid., pp. 498-499.

Definite spaces, preferably marked, should be reserved exclusively for: (1) moving; (2) stowing; (3) receiving; (4) assembling; and (5) shipping.

The clear and complete identification of each item is important. Identification of every item involves: (1) a tag for each lot; (2) a label on each unit or package, preferably on the end. Package identification marks should preferably face out, or be conspicuous.

Location of an item is governed by:

1. Difficulty of handling.
2. Quality to be carried.
3. Frequency of use.
4. Special considerations as of sensitiveness, perishability, or peculiar similarity to other items.
5. Safety (floor strength, fire hazard).

Immediate accessibility of items, lots and units, without rehandling means: (1) goods should be stowed in issuable units; (2) each item should be kept distinct. Therefore, a unit of one item or lot should not be stowed on top of or in front of a unit of a different item or lot. (3) Goods should be placed so that the greatest number of individual units or packages will show. This facilitates counting, as well as accessibility.

Fire proof buildings and bins, protection of windows and doors, accessibility of stores to hose streams and automatic sprinklers, are the most obvious means of protecting stores. Portable electric lamps should be enclosed in wire cages to prevent igniting inflammable goods when laid down on them for any length of time. Storesrooms should be of fireproof construction, particularly where their contents are inflammable. Not only are greater total values concentrated in them than elsewhere in the plant, but the greater volume of goods increases the fire risk.

Storage of inflammable material presents special problems. Where it must be stored in bins, these preferably are to be of metal or other fireproof construction, with automatic sprinklers in each bin. For certain classes of goods, such as oils, etc., foamite sprinklers should be supplied. Gasoline and fuel oil should be stored in underground tanks. The tanks should be vented to prevent accumulation of explosive gases in them. Explosives such as blasting powder and dynamite should be stored at a distance from all buildings. Storehouses for explosives, which should be used for no other purpose, should be of heavy masonry, with a light, flimsy roof. In event of an explosion the force will be expended through the roof without damage to the rest of the structure. Storage of explosives in cities is usually regulated by municipal ordinaces, and permits are required. Preventions from rust may be accomplished by slushing or painting.

CHAPTER VIII

ORGANIZATION AND MANAGEMENT

Fixing definite tasks and responsibilities in an organization is an absolute requirement to satisfactory cost and production control. Such practice is likewise a prerequisite to personal efficiency of every industrial executive. Concept of organization and included functions show that it is the means in industrial operation whereby the will of whoever makes decisions is put into effect.

Before any organization structure can be determined, certain fundamentals must be defined. These are: (1) policies; (2) authorities; (3) responsibilities; and (4) duties or activities.[1]

Policy - A code or general rule which states the established procedure to follow in a recurring situation.

Authority - The right of one person to require another person to perform certain duties or the right to act, decide, and command.

Responsibility - Responsibility is accountability for the performance of assigned duties. It is a moral attitude. Organization design calls for setting up LIMITS OF RESPONSIBILITY for each activity and effort.

Duties - The duties allotted to an individual are the activities he is required to perform because of the place he occupies in the organization. A duty may be called that which a person is bound by obligation to do. In industry, it is often called "a piece of work", "a job", "a task", or "a work assignment". In an organization sense, it is a contribution to the goal or objectivity.

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[1]L. P. Alford and J. P. Bangs, Production Handbook, p. 7.

An industrial organization structure must recognize (1) levels of authority and (2) degrees of responsibility. To be effective, these must have lines of communication, which include lines of authority and lines of response. The line of authority is from the top to bottom of the organization structure and the line of response is the reverse of the line of authority. (See Figure 8-1).

Work division is the foundation of organization. This means the division of work to be done into defined tasks and assignment of these tasks to individuals qualified by training and natural characteristics for their efficient accomplishment. The assignment of separate duties becomes necessary because (1) the volume or amount of work to be done in an industry becomes so great one man does not have sufficient time to execute his duties properly; (2) the capability, nature, and skill of men differ (if all decisions are to be rendered by one man, what will be the effect when he leaves the organization?); and (3) in most instances, one man does not have adequate knowledge of engineering, finance, manufacturing, sales, and controlling to administer the organization efficiently.

It is only fair to mention that work division has limitations, such as (1) disadvantage of subdividing work too minutely and (2) technology and custom make it unprofitable to subdivide certain kinds of work.

After determining the fundamentals of policy, authority, responsibility, and duties, set up a table covering:[2]

1. Degree of responsibility.
2. Level of position.
3. Range of duties.

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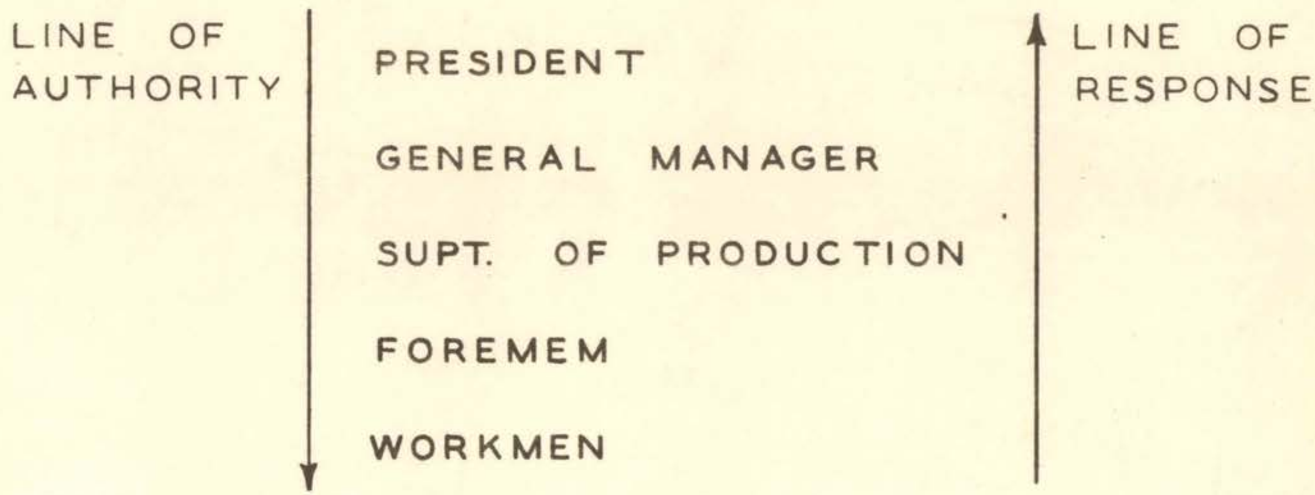
[2] *Ibid.*, p. 10.



LINES OF AUTHORITY AND RESPONSE

Figure 8-1

such as:

Degree of Responsibility	Level of Position	Range of Duties
1st	President	Administrative Policies
		General Management.
2nd	General Manager	Managerial Policies
		Managerial Control
3rd	Superintendent of Production	Operating Control
		General Control of Production
4th	Foreman	Detailed Control of Production
5th	Workmen	Performance of an Assigned Job

To these must be added assistants to help in the harmonious functioning of the organization.

It is not very difficult to make the proper division of work for most jobs in the establishment; however, determining responsibilities and assigning duties for cost oontrol, waste elimination, method improvement, quality maintenance, accident prevention, and service to customers is more difficult. Figures 8-2, 8-3, 8-4, 8-5, 8-6, 8-7, and 8-8 are examples of tables covering the salient points.[3]

Types of Organization

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[3]"Responsibility Charts", Management Information, (November 22, 1948 - November 29, 1948 - December 13, 1948 - December 20, 1948 - January 3, 1949 - January 10, 1949 - January 24, 1949), 4.

● *RESPONSIBILITY CHART*

WHOSE JOB IS WASTE ELIMINATION?

● Waste elimination is everybody's job. The whole organization shares responsibility — top management, supervisors and workers. Everybody has a stake in waste prevention. Less waste, lower costs. Lower costs, better business for the company, better record for the supervisor, and greater job security for workers.

WHAT NEEDS TO BE DONE	TOP MANAGEMENT'S RESPONSIBILITY	SUPERVISOR'S RESPONSIBILITY	WORKER'S RESPONSIBILITY
1. Spot the causes of waste.	To inform supervisors as to major types of waste. Undertake waste research.	**To check each job — operation by operation. List all possible causes of each kind of waste. Get right to the bottom of conditions resulting in waste.**	Each worker to check his own work. To consider each item as if his own money was being spent.
2. Count the costs.	To furnish supervisors with information, reports and records as to cost of waste in their departments, areas or sections.	**To acquaint each worker with the amount and cost of the waste on his own job, so that he will be waste-conscious.**	To make a sincere effort to reduce the cost of waste on his job.
3. Determine preventive measures.	To make studies by executives and staff specialist into the most effective ways to prevent waste and provide supervisors with guidance.	**To try out and check all practical means of preventing waste. To make sure that workers apply preventive measures.**	To follow preventive instructions as given by his supervisor.
4. Set up the right working conditions.	To provide conditions — space, layout, storage facilities, equipment, and specifications — which will make waste elimination possible.	**To make the best use of all waste prevention facilities. To see that good housekeeping, cleanliness and orderliness are maintained.**	To keep conditions right on his job. To notify supervisor of any conditions which create waste.
5. Use work methods that prevent waste.	To standardize methods, processes, and designs which will minimize waste.	**To see that the most economical work methods are carried out on each job.**	To follow instructions of the supervisor, and use the methods as directed.

Figure 8-2

RESPONSIBILITY CHART

WHOSE JOB IS IT TO CONTROL THE COST OF TIME?

Time is one of the costliest of items. It makes up a large part of the final cost of every product or service. We must all use time efficiently and economically.

What Needs to be Done?	*Top Management's Responsibility*	*Supervisor's Responsibility*	*Worker's Responsibility*
1. Understanding of the money value of time. 	To give supervisors up-to-date information on payrolls, and constantly impress upon them cost of idle time.	**To impart to workers how much time is worth—how much small items of idle time cost when totalled up.**	To give an hour's service for an hour's pay.
2. Time standards. 	To provide facilities and trained people who can study operations and determine how much work or service is expected in an hour's time.	**To be sure that a standard time is actually set for each job. To see that each worker knows what is expected from him each hour, day or week.**	To turn out the work which is the standard for the job.
3. Time records. 	To maintain a modern system of time keeping and recording.	**To study time records so that any failure to turn out the expected work is quickly detected and corrected.**	To cooperate in making the time records accurate.
4. Time savers. 	To employ some one who will constantly stimulate the discovery and application of time-saving ideas, methods and operations.	**To be on the lookout for ways to save time on every job supervised.**	To use the most economical time-saving methods on the job. To cut corners without cutting quality or service.
5. Close supervision. 	To devise over-all systems for checking supervisors as to the departmental cost results.	**To observe and eliminate any time-killing and wasting practices. See that workers follow time-saving methods as instructed.**	To follow job instructions—follow the time-saving way.

Figure 8-3

RESPONSIBILITY CHART

WHOSE JOB IS *Costs?*

● Costs are affected by the efforts of everyone in an organization. Top management, supervisors and workers are all responsible for costs.

WHAT IS NEEDED	 TOP MANAGEMENT'S RESPONSIBILITY	 SUPERVISOR'S RESPONSIBILITY	 WORKER'S RESPONSIBILITY
1 EFFICIENT WORKERS	To provide conditions which will attract and hold good workers.	**To train workers well, arouse their interest in efficiency, win good will and see that they are rewarded for their productivity.**	To do a good day's work for a good day's pay. To work savingly, with a minimum of waste.
2 MODERN EQUIPMENT	To keep plant and operations equipped with efficient machines, tools and facilities.	**To see that equipment is used at maximum productivity, so that unit cost will be kept at minimum.**	To operate equipment so that its maximum productive capacity is realized.
3 ECONOMICAL METHODS	To lead the drive for constant improvement in methods.	**To constantly seek to develop the most efficient methods of doing work. To teach these methods to workers.**	To follow economical work methods as instructed.
4 CAREFUL PLANNING	To set up systems for over-all planning which will make economical utilization of men, plant and equipment possible.	**To carefully schedule departmental operation so as to minimize idle time of workers and equipment. To use equipment and workers to best possible advantage.**	To use each hour productively. To plan work to save time, material and power.
5 CLOSE CONTROL	To establish cost control methods which will spotlight any wasteful or costly methods or operations.	**To supervise closely all workers, methods and operations so that excessive cost is spotted and corrected promptly.**	To do work so that the least possible cost is involved. To help keep costs within prescribed limits.

Figure 8-4

Whose Job Is It to Make Work Easier and Simpler?

• There's nothing to be gained by doing work the hard way. If an easier and simpler way can be found, efficiency will be increased, waste effort eliminated and better results will be obtained at lower costs to the customer. Goods and services are more salable when produced and delivered at the lowest possible cost.

R E S P O N S I B I L I T Y   C H A R T

WHAT NEEDS TO BE DONE	TOP MANAGEMENT'S RESPONSIBILITY	SUPERVISOR'S RESPONSIBILITY	WORKER'S RESPONSIBILITY
1 RECOGNIZE THE WORTH-WHILENESS OF DOING WORK IN THE SIMPLEST AND EASIEST WAY.	To advertise the fact throughout the organization that top management seeks easier and simpler ways of getting work done.	**To make understood that any present method will be gladly changed if a simpler and easier way can be suggested.**	To be willing to change the present method. To be open-minded about changes.
2 LOOK FOR EASIER, SIMPLER METHODS.	To constantly encourage people to look for ways to simplify work.	**To constantly look at present methods with a critical eye. Ask, "is this the easiest way, the simplest way?"**	To make suggestions for simplifying his own work, and show a willingness to use time saved for other useful purposes.
3 STUDY INDIVIDUAL JOBS.	To check supervisors to see that they have a plan for systematically studying individual jobs to discover easier, simpler ways to get standard results.	**To make the rounds, job by job, making a thorough analysis of each job so that no opportunity for simplification is overlooked.**	To look critically at the details of the present method. To figure out a better way — easier, simpler.
4 MAKE IMPROVEMENTS PROMPTLY.	To impress upon supervisors that a postponed improvement constitutes a needless cost.	**To put easier, simpler methods to work just as soon as possible.**	To cooperatively accept new methods and refrain from any delaying action in getting the benefits of simplification.
5 KEEP ON IMPROVING WORK METHODS.	To keep interest alive in making improvements. To make it clear to all that improvements in work methods makes the company more competitive and jobs more secure.	**To start all over again as soon as the rounds have been made. Act on the principle that a still better way can always be found.**	To accept the fact that the one constant thing is *change*. That his own job is safer and more secure if it is being done in the most efficient way.

Figure 8-5

RESPONSIBILITY CHART

WHOSE JOB IS *quality?*

To produce a product or render a service which measures up to high quality standards everyone must do his part. It only takes one person to spoil the quality work of many careful workers.

WHAT IS NEEDED	TOP MANAGEMENT'S RESPONSIBILITY	SUPERVISOR'S RESPONSIBILITY	WORKER'S RESPONSIBILITY
1. Quality standards must be set and understood.	To establish definite specifications for the product or service and determine what tolerances are permissible.	***To know the required standards and clearly inform workers as to quality standards expected of them.***	To have a clear understanding of minimum quality standards before starting to do a job or meeting a customer.
2. Proper materials.	To buy the kind of materials from which a quality product can be made.	***To see that the specified material is issued to workers and make sure they use it.***	To use the correct material specified for the job.
3. Proper tools and equipment.	To provide the right tools, machines and equipment.	***To see that right tools and equipment are used on each job, and that they are kept in proper condition and adjustment for quality work.***	To use the correct tools and equipment, and immediately report any need for repairs or adjustment.
4. Quality work methods.	To standardize methods and processes which will give quality results.	***To help in the development of quality job methods and thoroughly instruct workers in the quality methods.***	To do the work in the manner exactly as instructed.
5. Quality working conditions.	To provide working conditions which will encourage quality workmanship.	***To keep work areas orderly, safe, clean and shipshape. To treat workers so that good-will and co-operation are maintained.***	To share and cooperate in maintaining good conditions, orderliness and cleanliness.

Figure 8-6

RESPONSIBILITY CHART

Whose Job is Safety?

Safety is not a one-man job – it's everybody's job every minute of every day. Safety is part of every job in every kind of business and industry – in the shop, on the highways and railways, in the store, in the mine – everywhere.

WHAT NEEDS TO BE DONE	TOP MANAGEMENT'S RESPONSIBILITY	SUPERVISOR'S RESPONSIBILITY	WORKER'S RESPONSIBILITY
1 SELL SAFETY	To impress all with importance of safety. To put safety on equal level of importance with other functions. To give credit to supervisors who take safety seriously. To advertise and posterize safety throughout the organization.	**To show every worker what safe work means to himself, his family and fellow workers. To make full use of counsel and aids made available by safety department or top management.**	To heed safety instructions and help to impress fellow workers with importance of safety. To set a good example to new workers.
2 SPOT ACCIDENT CAUSES	To give supervisors full support and staff assistance in analyzing the causes of accidents.	**To constantly observe, inspect and detect any conditions, work habits, or attitudes which might cause an accident.**	To be alert to spot possible accident causes and report them immediately.
3 REMOVE HAZARDS	To be ready to correct or safeguard every hazard.	**To act promptly in removing any hazard. To safeguard the hazards which can't be removed. To instruct workers thoroughly in the safe way to perform hazardous work.**	To keep the work place as free of hazardous conditions as possible. To request help to remove hazards and correct conditions beyond his own authority and control.
4 SET AND MAINTAIN SAFE WORK STANDARDS	To make sure that every supervisor is doing his duty in prescribing safe work methods, rules and regulations. To back up the supervisor in the enforcement of safe work standards.	**To determine the safe way to do each job. To enforce rules and regulations. To make certain that every worker knows the safety standards on his job.**	To follow safety instructions, rules and standards.
5 FOLLOW UP	To keep alive the interest in safety by constant emphasis on importance of safety. To hold supervisors accountable for all accidents.	**To develop a plan for periodic safety contacts with each worker. To inspect regularly. To set a constant safety example. To devise ways to keep safety work interesting.**	To avoid overfamiliarity with hazards. To avoid chance-taking. To remember that the law of averages applies to injuries – that an unsafe act committed frequently will surely end in an accident eventually.

Figure 8-7

WHOSE RESPONSIBILITY IS SERVICE TO THE CUSTOMER?

Actually, we all work for the customer. The customer is the one we must all serve. If the customer is not satisfied he will spend his dollars elsewhere. If we deliver poor quality products or service, the customer will seek some other source to satisfy his needs.

WHAT NEEDS TO BE DONE	TOP MANAGEMENT'S RESPONSIBILITY	SUPERVISOR'S RESPONSIBILITY	WORKER'S RESPONSIBILITY
1 DETERMINE WHAT THE CUSTOMER WANTS	To survey and analyze customer requirements, tastes and demands.	**To thoroughly familiarize himself with all information available as to what will best satisfy customers.**	To put himself in the customer's shoes.
2 MAKE IT CLEAR THAT THE CUSTOMER IS "BOSS"	To keep constantly before the entire organization the fact that business and jobs depend upon satisfied customers.	**To drill into the minds of each individual employee how dependent the employee is upon the continued patronage of customers.**	To do his work so that the customer will get full value for his dollar.
3 SET HIGH STANDARDS OF QUALITY AND SERVICE	To know the quality of products and service provided by competition, and set standards equally high or higher.	**To see that quality standards and customer service are maintained at highest level.**	To live up to the standards set.
4 LET EVERYONE KNOW HIS PART IN SERVING CUSTOMERS	To hold supervisors accountable for their part in customer service.	**To instruct each employee carefully in how to do his work so that quality products and service are delivered.**	To know how his own performance affects the quality of service to customers.
5 DELIVER TO SUIT THE CUSTOMER	To establish controls, plans and schedules that will insure deliveries on time, at the right price and in the desired quantities.	**To plan, to layout the work, to keep work up to schedule and to vigorously avoid any slip-up that will inconvenience a customer.**	To do work punctually, to meet customers courteously, to give the customer the quality and service he expects.

Figure 8-8

Attempts have been made to classify and identify various forms of organization. It is unlikely that any one of these as such can be found in any manufacturing organization. Rather, organization of industrial concerns will be a composite of various forms, the particular variation or combination being dependent upon the existing conditions. The four elemental types of industrial organization which are recognized are these:

1. Line or military organization.
2. Functional organization.
3. Line and staff organization.
4. Committee organization.

Line or Military Organization

This is probably the oldest and most common form of organization. It is also the most natural, being based on the ancient military organization and not the modern army organization.

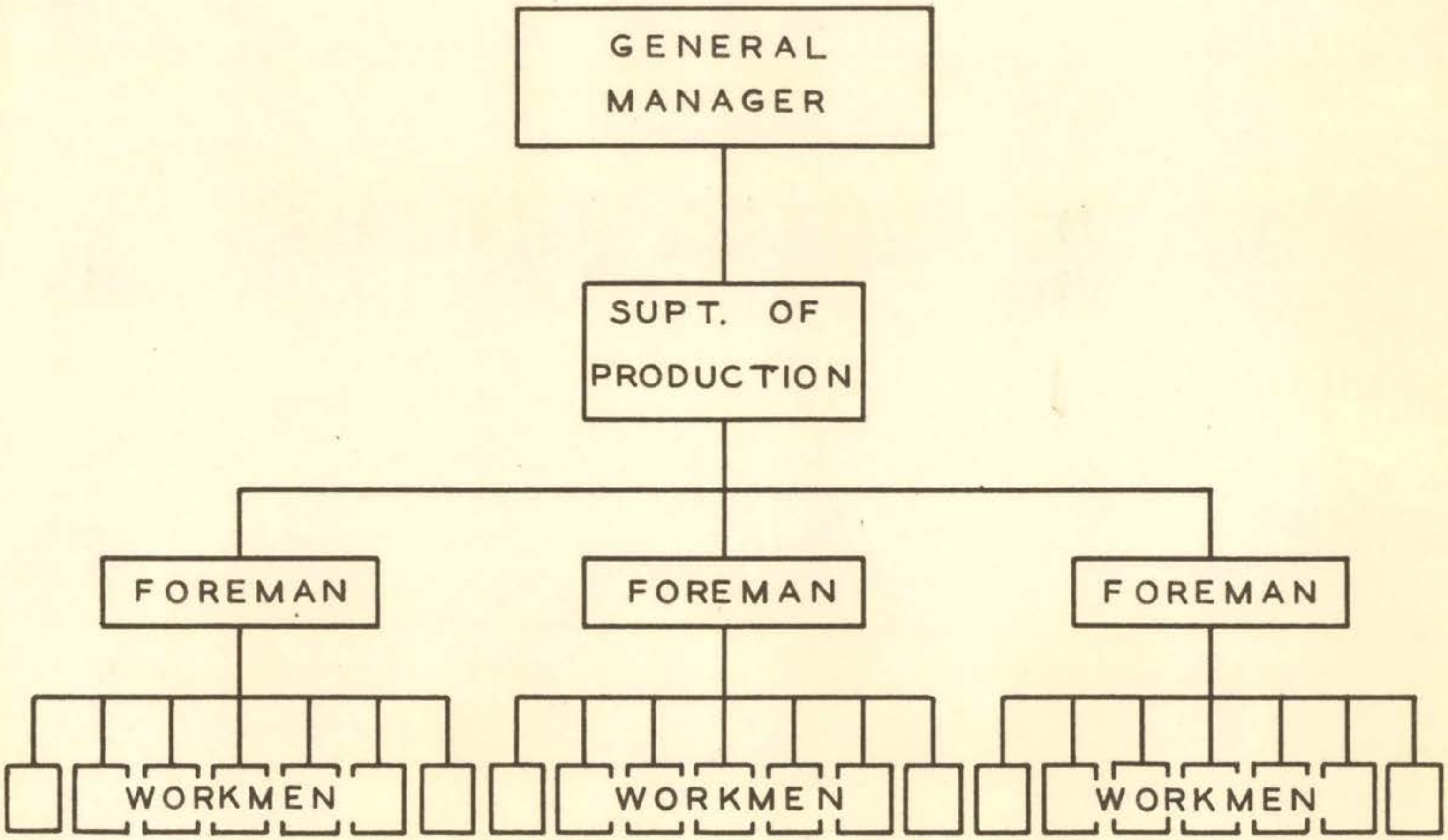
Lines of authority and instruction are all vertical extending from superior to subordinate as shown in Figure 8-9. Duties and responsibilities may be deputized from general manager to superintendent and from superintendent to foreman. No foreman exercises authority over or gives instruction to any other foreman; no workman owes duty to anyone except his own immediate supervisor.

Advantages of this type organization are simplicity, clear definition of duties and responsibilities, and ease of securing discipline.

Disadvantages are rigidity and inflexibility, difficulty of operation in complex undertakings, overloading a few men, disaster if top executive is lost, and necessity of passing instructions along a series of executives.

Functional Organization

The functional form has been developed to make use of expert knowledge and



LINE OR MILITARY TYPE ORGANIZATION

Figure 8-9

advice. Mental and manual work is subdivided and deputized as shown in Figures 8-10 and 8-11. In the example, the chemist gives advice to all foremen on chemical matters, the engineer or engineering matters, and the superintendent on matters in regard to actual production.

Lines of authority and instruction pass from each advisor to every functional foreman and from each functional foreman to every workman. Duties of the foremen may be quite different, for each may have charge of but a certain aspect of the work. Different instructions will be received by the workmen from each foreman.

Advantages of this type organization are separation of mental and manual duties, maximum of expert advice, minimum of functions assigned to any one person, and high individual efficiency.

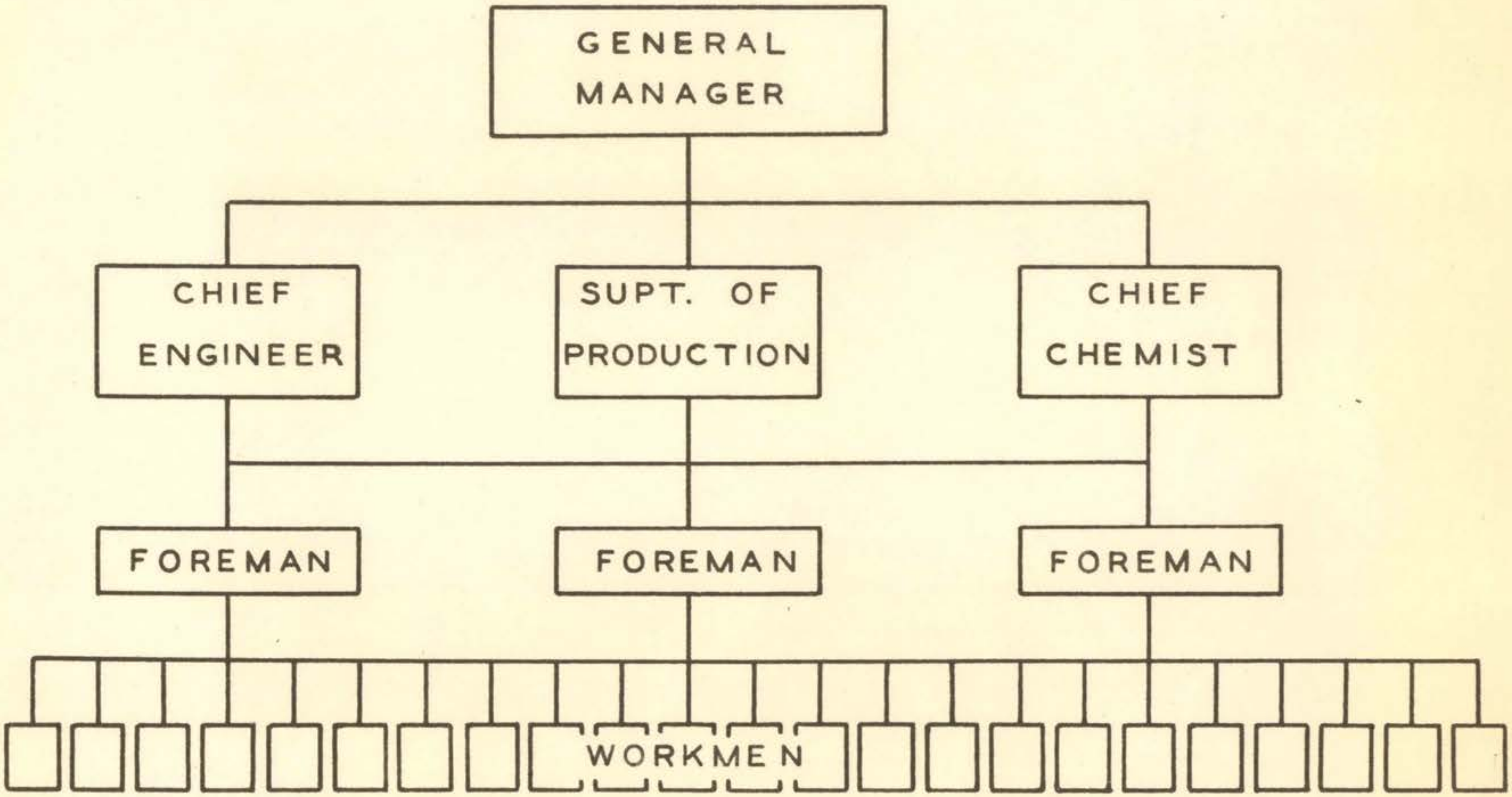
Disadvantages are weak discipline, difficulty of coordinating separate functions, and tendency to produce narrow specialists among executives and automats among workers.

Line and Staff Organization

This type arrangement combines features of both line and functional types. Figures 8-12 and 8-13 show the general plan. This arrangement makes a clear distinction between doing and thinking. It permits a specialization by desirable functions but maintains integrity of the principle of undivided responsibility and authority.

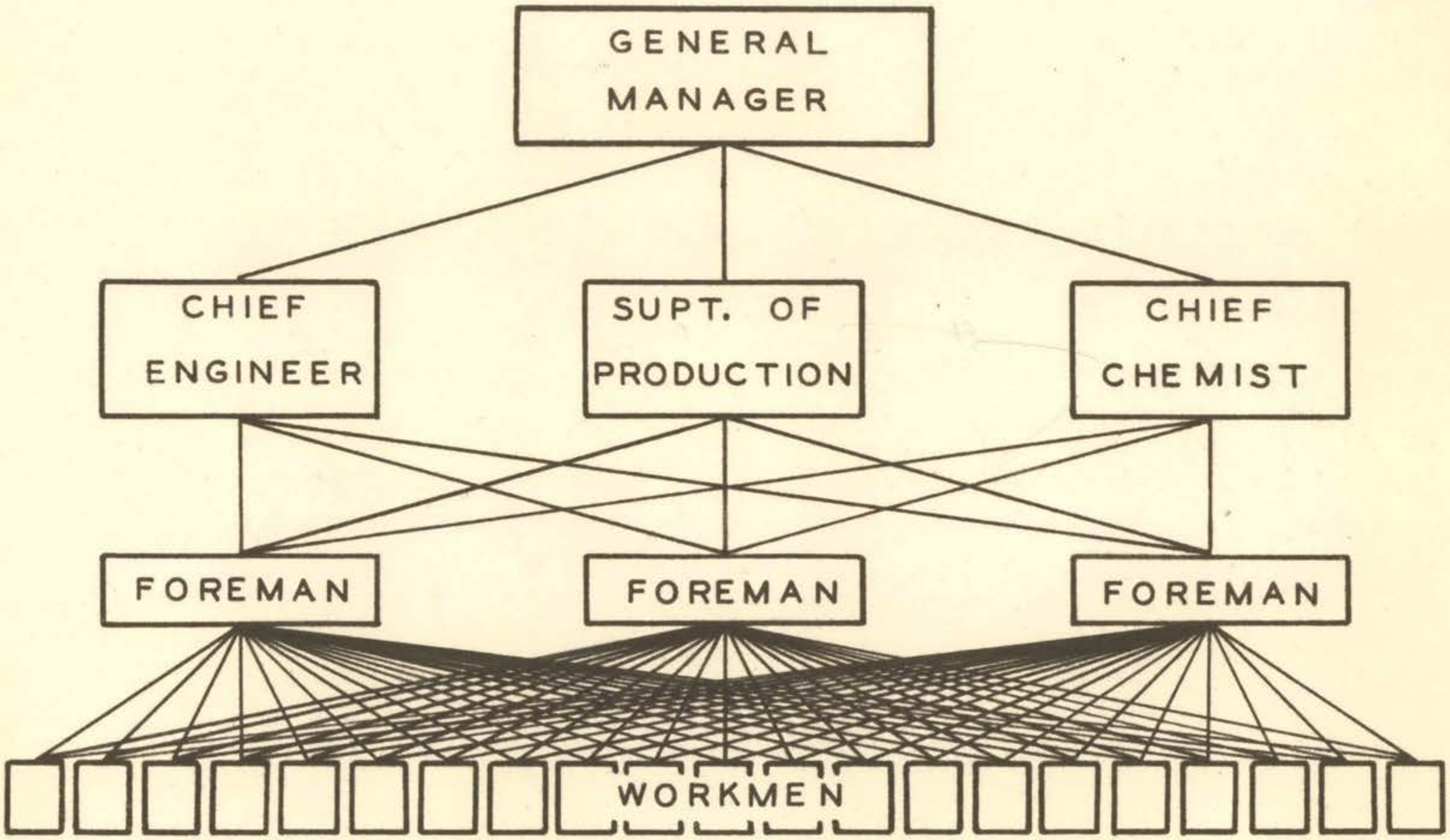
The line element serves to maintain discipline and stability, and the staff serves to bring in expert information. The staff function is strictly advisory and carries no power or authority to put its knowledge into operation.

Lines of authority and responsibility are vertical for line executives having least complex duties and spread from staff advisory to line executive wherever expert knowledge and counsel are needed.



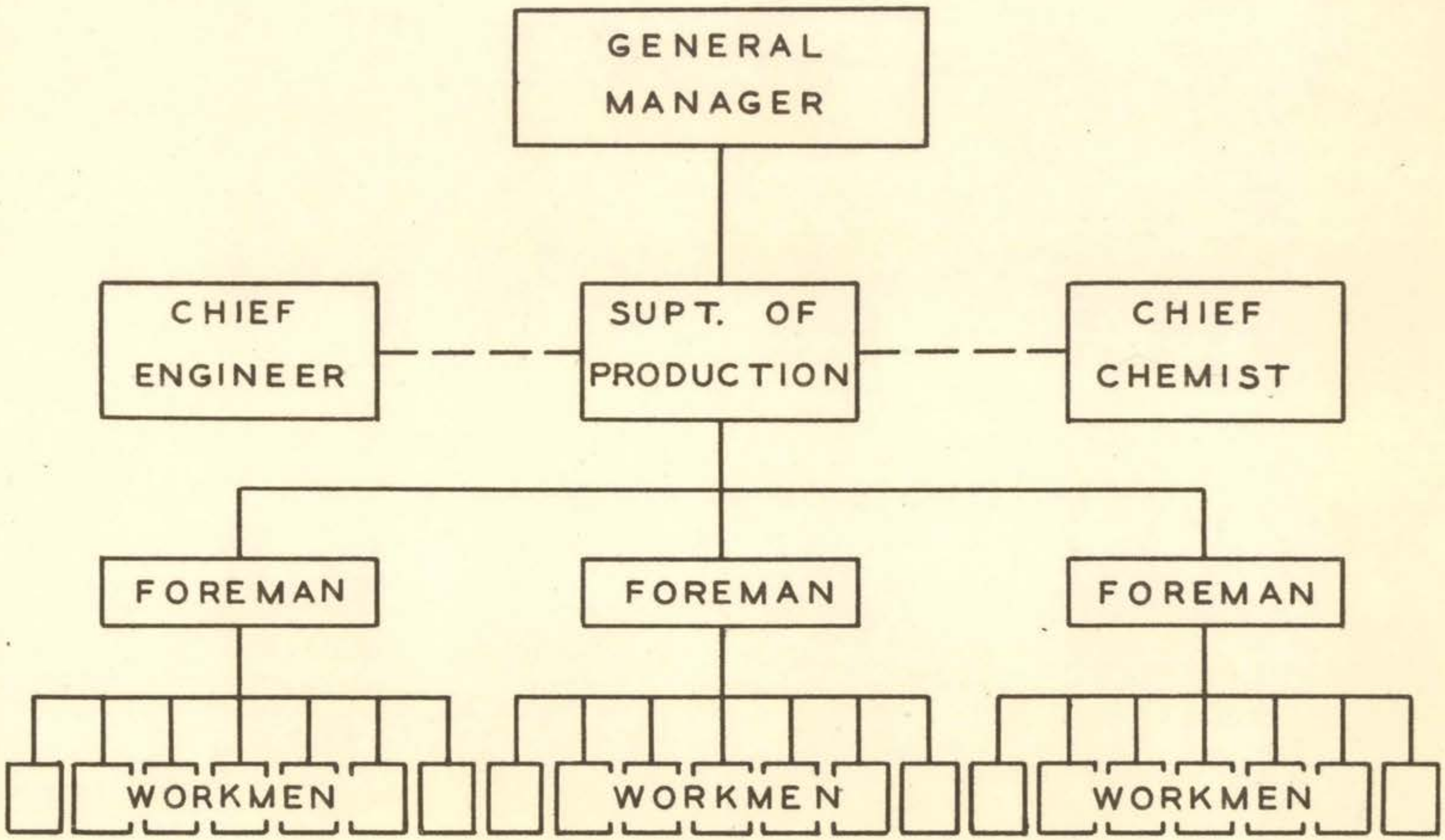
FUNCTIONAL TYPE ORGANIZATION

Figure 8-10



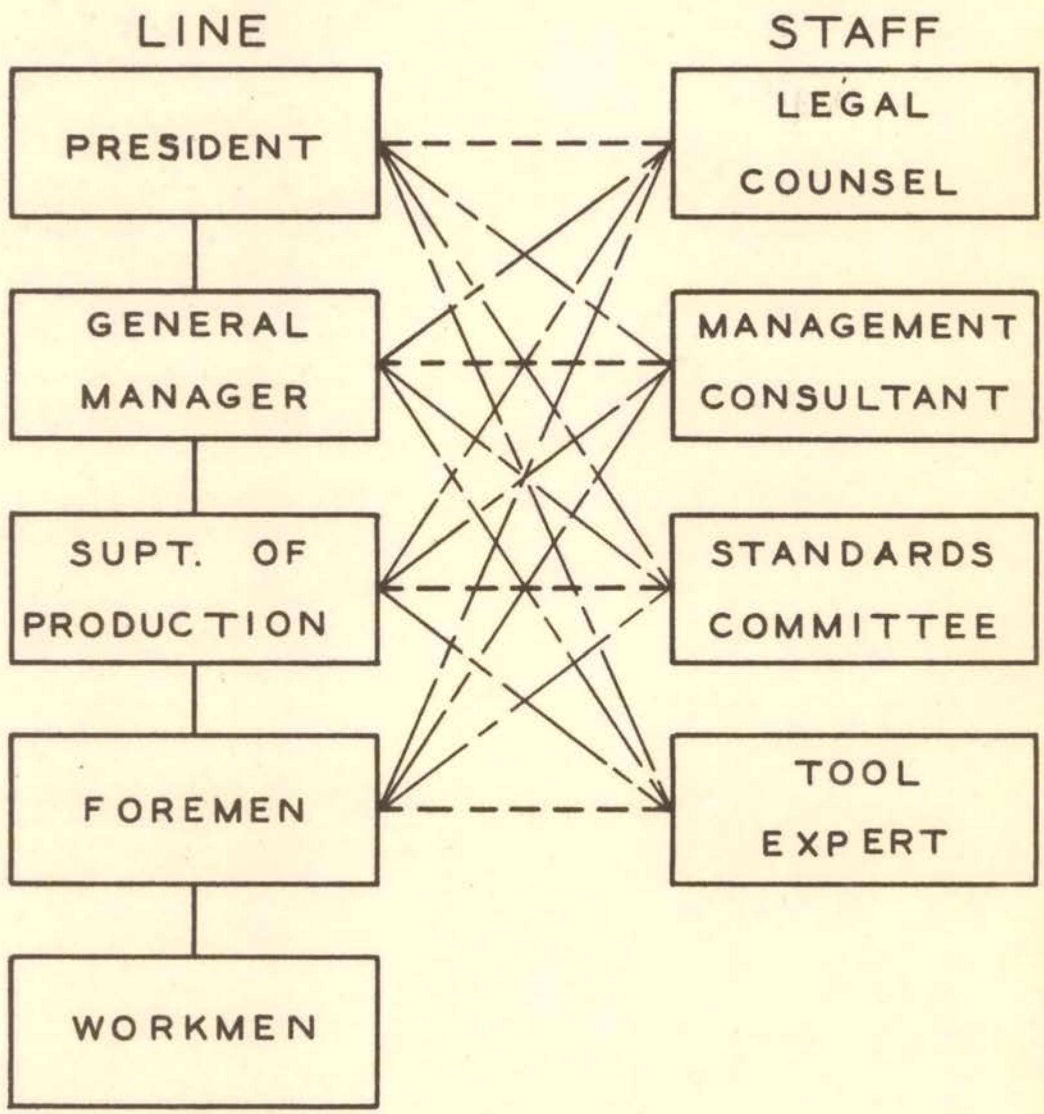
RELATIONSHIP IN A
FUNCTIONAL TYPE ORGANIZATION

Figure 8-11



LINE AND STAFF TYPE ORGANIZATION

Figure 8-12



RELATIONSHIP IN A
LINE AND STAFF TYPE ORGANIZATION

Figure 8-13

In general, advantages of this type of organization are: based on planned specialization, expert knowledge of management and operating problems, more opportunity for advancement for able workers in that a greater variety of responsible jobs are available, makes possible the principles of undivided responsibility and authority and at the same time permits staff specialization, and repays its added costs many times due to increased efficiency of operations.

Disadvantages are: Unless duties and responsibilities of staff members are clearly indicated by charts and manuals there is too much confusion, staff may be ineffective for lack of authority, friction between line supervisors and staff members unless they see alike, expert advice since it goes through supervisors may be misinterpreted before getting to the workers, and resentment by the line supervisors.

Committee Organization

This is a modification of line and staff type where advisory functions are exercised by committees. (See Figure 8-14). The committee organization is supplementary to both line organization and line and staff organization.

The committee is purely an advisory group. It is (1) set up to investigate operating problems or questions which arise from time to time, (2) set up to make recommendations or formulate procedures, and (3) set up to turn results to proper executives or supervisors who may be members of the committee for action.

Typical committees in a small organization might include general purchase control, quality, and scheduling.

Organization Charts

The next step is to prepare an organization chart. These may vary to meet each individual's need, but normally basic patterns are followed.[4]

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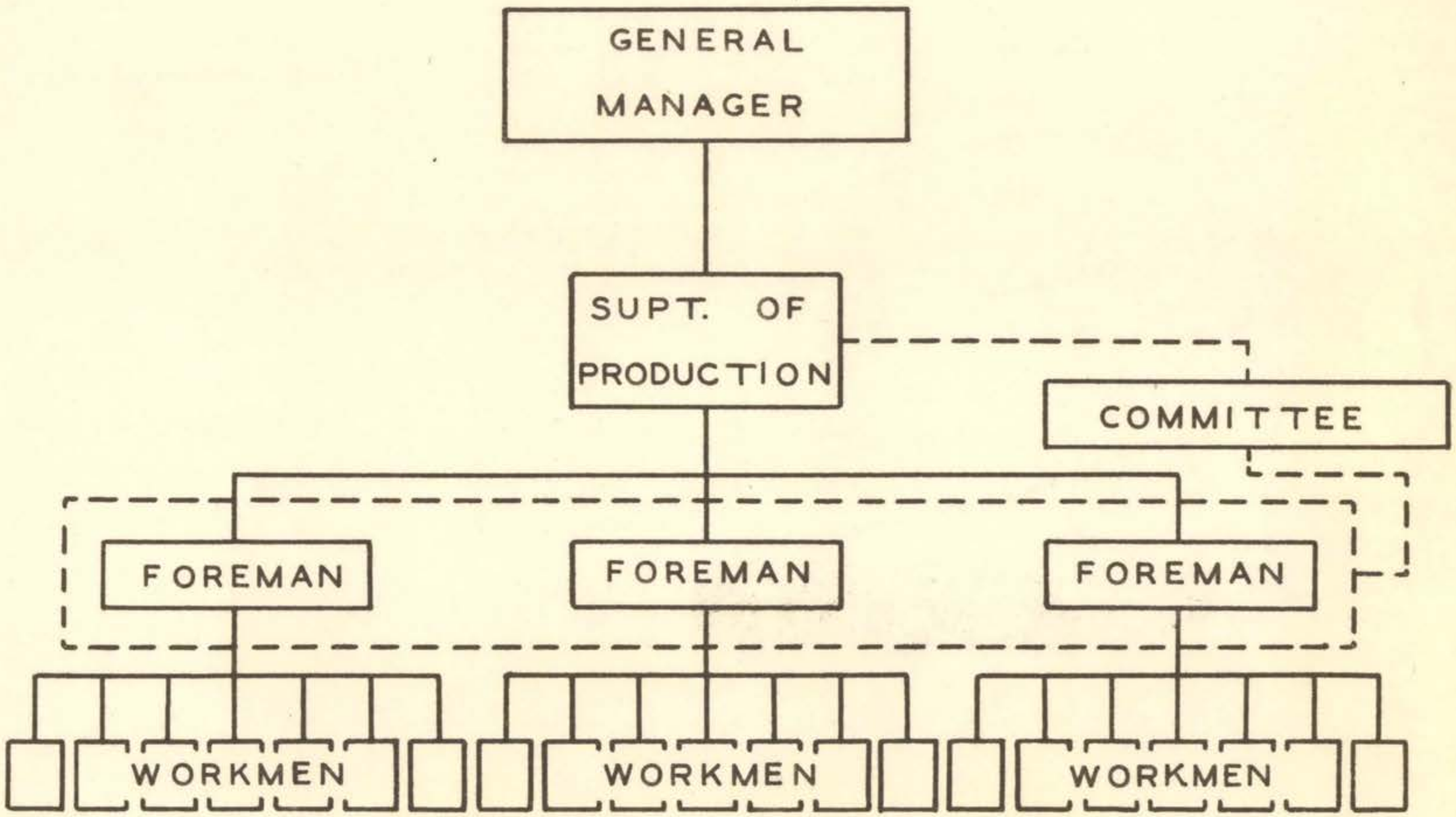
[4]Alford and Bang, *op. cit.*, p. 42.



COMMITTEE TYPE ORGANIZATION

Figure 8-14

In Figure 8-15, the most common form is represented by Charts A and B. Chart C is a variant used to save space. Chart D is commonly found in telephone companies. The boxes often include total number under the direction of each executive at various levels. Chart E is a new form which has been presented by Mr. Ralph T. Finnell in the October 1947 issue of Factory Management and Maintenance.

Who is in charge of what, and who is supposed to report to whom is always easy to find and is quickly available from the "pie chart" organization plan illustrated in Figure 8-16.

The semicircular organization chart makes it easy for everyone to follow the lines of authority and responsibility from the president to the lowliest helper.

The typical departmental organization illustrated shows the variety of sectional arrangements within the large groups that can be properly classified. Any sectional group that might be responsible to two men on the next level of management can be shown below the segment where the two top men are placed next to each other on their own level. The line dividing the activities of the two men is then placed in the center of the section in the lower level.

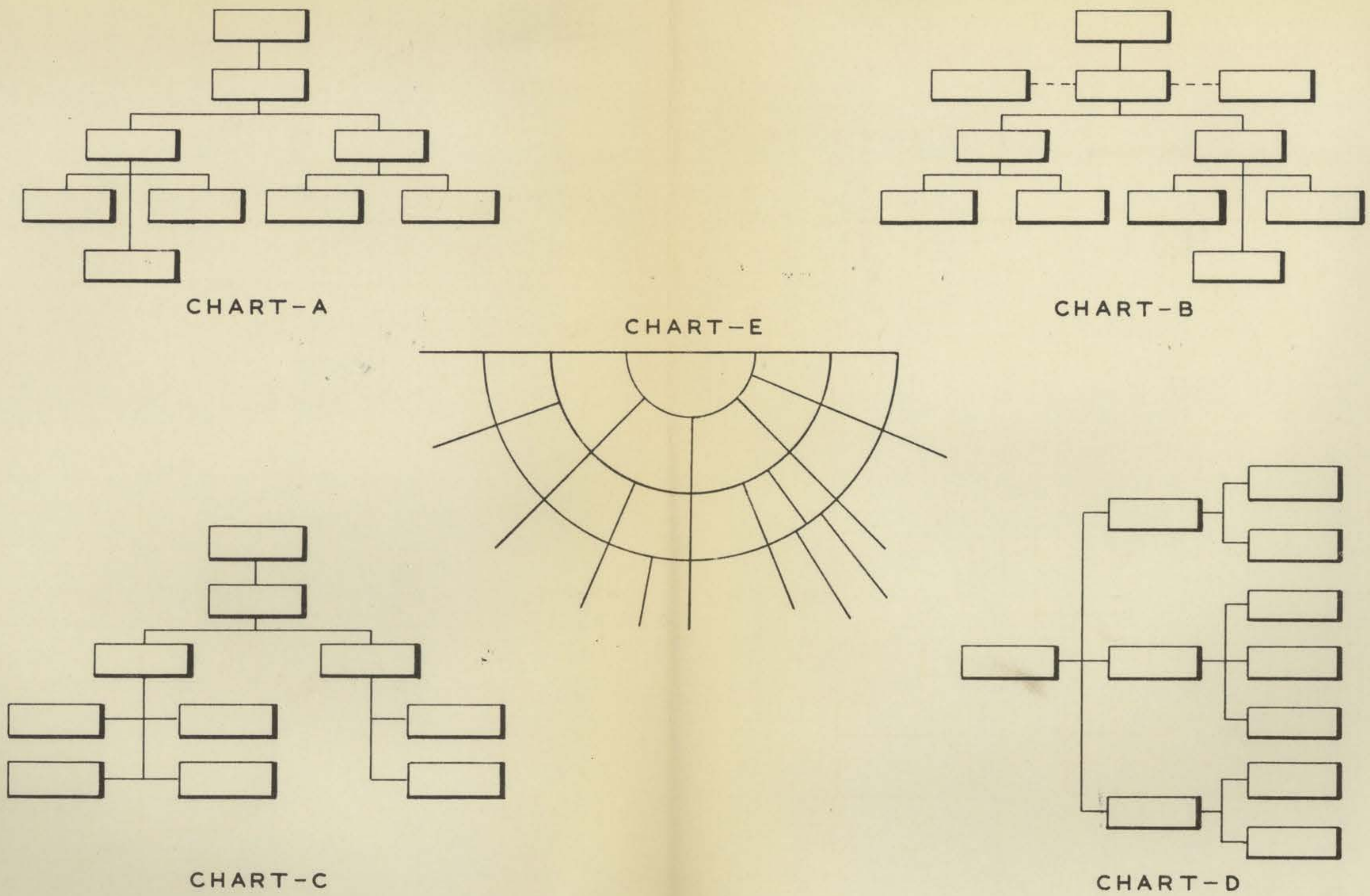
Procedure and Standard Instructions

From the information shown on the organizational chart, a standard operating procedure can be established and a permanent record prepared in the form of standard practice instructions. These instructions show the duties to be performed, by whom, they are to be performed, the sequence in which they occur, and the forms involved.

Assignment of Personnel

With the completion of the next instructions in the form of an organization manual, the next step is to determine the number of persons of each

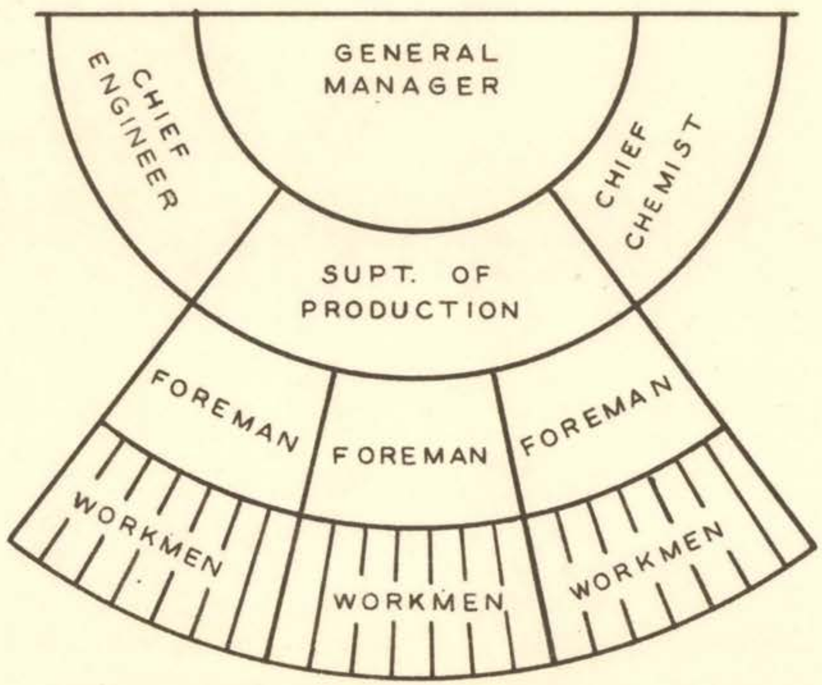
TYPES OF ORGANIZATION CHARTS



——— SOLID LINE SHOWS DIRECT FLOW OF AUTHORITY

- - - - BROKEN LINE DOES NOT SHOW DIRECT LINE AUTHORITY

Figure 8-15



LINE AND STAFF TYPE ORGANIZATION

Figure 8-16

classification required for any given workload under the procedure. To determine the number of personnel needed for operations, it is necessary to start at the bottom of the organization and build toward the top. First determine the number of workmen needed to perform all the operations. After the step has carefully been completed, the number of first level supervisors may be determined. The principle of the span of control should be considered in this second step, as well as in all steps that follow. When the number of first line supervisors has been determined, continue up the organization until all the line supervisors have been established. By using the same procedure, the number of personnel required for staff functions may be determined.

Summary

In summary, the steps in the establishment of the organization and management are these:

1. Define fundamentals.
2. Determine degree of responsibility, level of position, and range of duties.
3. Select the type of organization.
4. Draw organization chart.
5. Establish procedure.
6. Establish standard practice instructions.
7. Determine number of persons of each classification required for any given workload under the procedure.
8. Select the personnel to fit the organization.

CHAPTER IX

PICKING A PLANT SITE

All over the country, astute progressive companies are deserting the congested industrial sections of cities. They are building new plants out where land, light, and fresh air are at no premium. Modern flexible transportation and efficient communication are largely responsible for industry's ability to take a step of this sort.

General Considerations

The location of an industrial plant is often the result of a compromise among conflicting social, governmental, geographic, and economic considerations.[1]

The decision regarding plant location often involves very large commitments of a relatively fixed nature and limits the adjustment of the enterprise to changing conditions; therefore, the picking of a plant site should not be made until all factors have been carefully analyzed.

Alford's Principle

Alford's principle of industrial plant location states that the most advantageous location for a plant for an industrial enterprise is the one where the sum of manufacturing and distributing costs are at a minimum.[2] This principle only takes into account the economic and geographical considerations. In the complex society in which an enterprise has to function today the other two--social and governmental--often become the controlling factors. In no case can they be omitted.

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[1] W. R. Spriegel and R. H. Lansburgh, Industrial Management, p. 37.

[2] L. P. Alford, Principles of Industrial Organization, p. 124.

Plant Location

The success or failure of an industrial enterprise is dependent upon the location of the plant. If it is located wrong the management is greatly handicapped in meeting competition of a company whose plant is located correctly.

Detail Breakdown of Factors

The listing that follows is some of the important factors, classified under the various factors of management, that must be evaluated before a final decision can be properly made as to the location of a plant:[3]

1. With reference to money:
    a. The capital available for investment.
    b. Financial aid from the community.
    c. The value of land.
    d. Construction cost.
    e. Taxes.
2. With reference to workmen:
    a. The supply and value of labor.
    b. Accessibility of the plant to workers.
    c. Favorable climatic conditions.
    d. Sanitary, fire and police protection facilities.
    e. Housing facilities.
3. With reference to materials:
    a. The nearness to and availability of materials.
    b. Electric power, light, gas and water supply.
    c. Buildings available.
    d. Facilities for the disposal of waste.

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[3] J. E. Walters, Modern Management, p. 200.

e. Climatic conditions for the manufacture of the material.

f. The character of the site.

4. With reference to marketing:

a. Nearness to and accessibility of the markets.

b. Transportation facilities.

c. Dependence upon other industries.

d. Relative values of local markets.

5. With reference to general management methods:

a. The momentum of an early start.

b. The initial building requirements.

c. Possibilities for expansion.

d. Community restrictions and aid.

e. The favorableness of industrial laws of the state--towards labor, sales tax, corporation tax, etc.

f. General taxes.

CHAPTER X

SELECTION OF TYPE OF BUILDING

In determining the ultimate cost of a complete plant or single industrial building as affected by the type of structure selected, consideration must be given in most cases, to the relative merits of Multistory and Single Story buildings.

Engineers have made studies of the advantages and disadvantages of these two distinct types of industrial buildings and their findings are helpful to manufacturers analyzing their building problems.

The following comparison of the relative advantages and disadvantages of Multistory and Single Story Factory Buildings was taken from studies made by The Austin Company, builders of both types of buildings.

Construction Cost

Based on a substantial floor loading per square foot, the same natural light per square foot and the same cubical contents per square foot of plan, it can be seen by referring to Figures 10-1 and 10-2 that the cost of a Single Story building of the same gross area as a Multistory building is considerable less expensive per square foot. In making these comparison charts, the items that follow were considered:

1. The elevators, elevator shafts and walls enclosing them add to the cost of a Multistory building. Most large Multistory buildings require either two freight elevators or one passenger and one freight elevator.

2. Most Multistory buildings require a stairway at each end of the building to comply with building codes. These usually must be enclosed in fire walls to meet building code specifications, and these walls, together with the stairs, involve expenses amounting to several thousand dollars. When only one stairway is used, outside fire escapes must be provided.

3. Heavy live load requirements on several floors increase cost. In a Single Story building, depending of course upon the

RATIO COMPARISON CHARTS OF COST OF MULTISTORY AND SINGLE STORY BUILDINGS

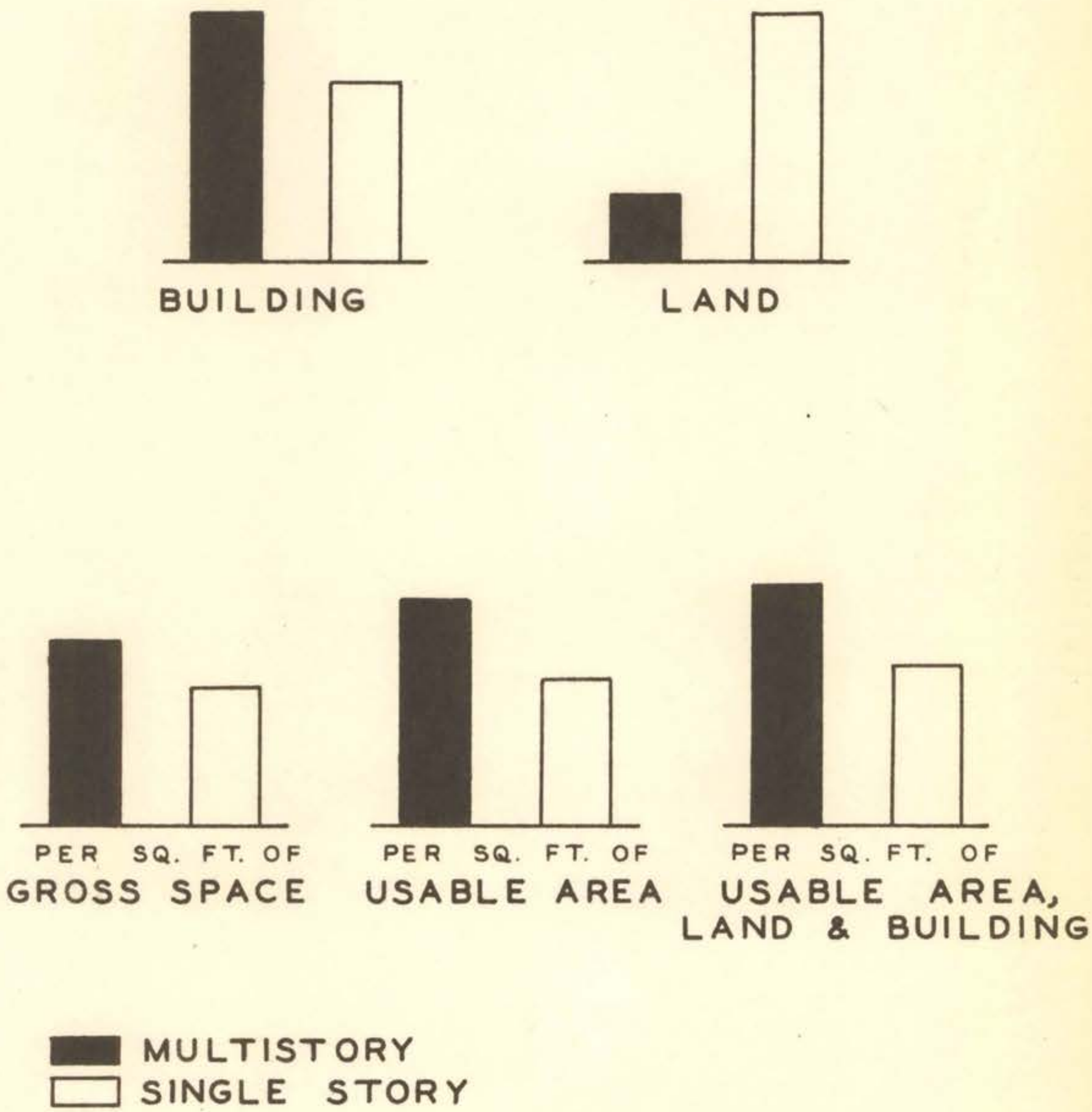

Figure 10-1

RATIO COMPARISON CHARTS OF LOST SPACE IN MULTISTORY AND SINGLE STORY BUILDINGS

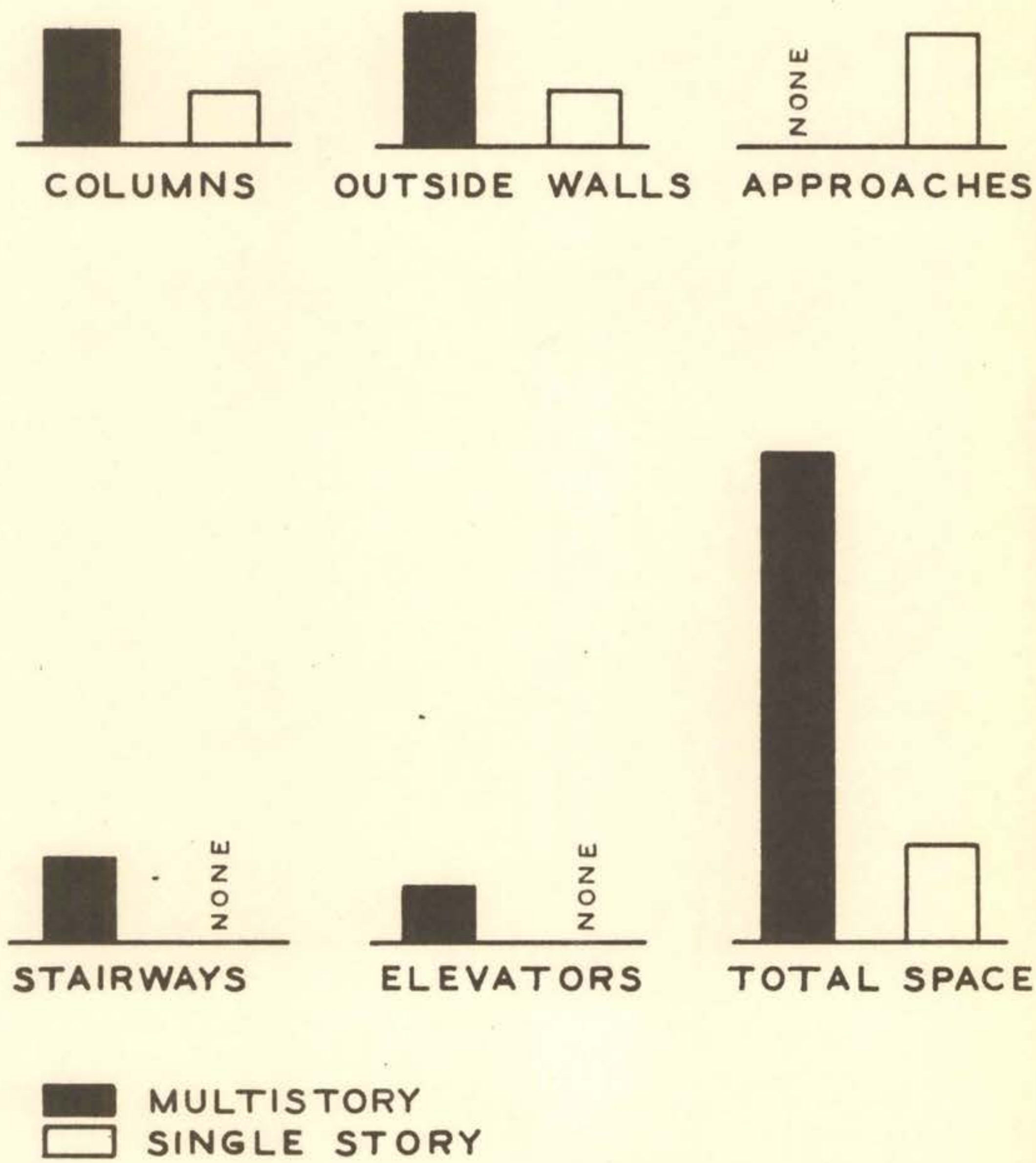

Figure 10-2

bearing value of the soil, there is, for all practical purposes, no limit to the load the floor will carry safely.

4. The combined cost of the roof, and the floor which rests on the earth in a Single Story building, does not exceed the cost of the structural floor which serves as a floor and ceiling, in the Multistory type.

5. The cost is more for labor and materials, for the building proper, in the Multistory type, than for these same items in a Single Story building of the same gross area and based on the same assumption of natural light, loading and cubical contents per square foot of plan.

From every standpoint the cost of usable floor space is of vital importance. A building represents an investment and returns on the capital invested depend largely upon the selection and arrangement of the building. In a six-story building of 72,000 square feet there is approximately five times as much waste floor space as in a Single Story building of the same gross area. When there is a maximum of unobstructed usable floor area in a building of a given gross area then that building will pay the highest dividents for every dollar invested. It is not the volume of building materials in a structure that counts, it is the well-lighted usable floor space in areas practical for ideal working conditions. In a Single Story building the construction cost of usable floor area is approximately 25 percent less per square foot than in a Multistory building of the same gross area.

Operating Costs

Manufacturers are beginning to realize that operating costs are usually more in a Multistory building than in a Single Story building. Studies have shown that:

1. Less time is lost in handling materials in Single Story buildings than in a Multistory buildings, where elevators must be used.

2. A Single Story building saves about 20 percent of superintendents', managers' and other employees' time. Supervision of a factory situated on one floor is easy because a clear view from one end of the building to the other is usually possible.

If one man must supervise all floors in a Multistory building a large part of his time will be spent in following materials and men from one floor to another. When it is necessary that men be located quickly in a Multistory building, an automatic calling device must be installed.

3. A more efficient use of materials handling equipment is usually possible in a Single Story building--straight line production, with raw materials entering at one end of the building and the finished units emerging at the other with materials in a constant process of manufacture. However, for the manufacture of certain products a Multistory building may be desirable.

4. The uses of the upper floors of a building are necessarily limited by the size or weight of the products that can be handled by the elevators.

5. Beside the time lost in handling products on elevators there is also the expense of operating the elevators during each year of the life of the building.

6. Labor cost to operate the elevators is usually an important item, this is the case whether they are running at all times or not.

7. The expense of electric power necessary to move heavy loads on elevators from one floor to another must be considered.

8. The cost of maintenance and repairs is continuous from the time elevators are installed.

9. In a Single Story building, materials can be delivered to or shipped from any department direct. In a Multistory building this is obviously impossible.

10. Single Story buildings are usually erected away from congested districts and high land values. Switching service from the railroads is better because there is less freight congestion.

11. Where manufacturing requirements will permit, stockroom facilities can be combined in a Single Story building.

Single Story buildings have the advantage of flexibility due to their design. A new product can be added to a manufacturer's line with the minimum of change in this type of building.

<u>Time Required to Build</u>

It is a generally accepted fact that a Multistory building requires a longer time to build than a Single Story building of the same floor area.

Production operations can be started earlier in a Single Story building than in the Multistory type.

The Land Factor

The general tendency is to move from highly congested districts and high taxes. For some industries, whether the land costs $5,000 or $50,000 an acre, a Single Story building is most economical and most efficient. Under present methods of auto and truck transportation the factory located on the outskirts of a town or city has many advantages.

Light, Heat and Ventilation

Good lighting, both natural and artificial, and abundant ventilation contribute to increased production. In a Single Story building the entire floor area is well lighted while in Multistory buildings the well-lighted areas are limited to the areas along the outside walls, and for the interior floor areas artificial lighting is required with continuous expense. The same conditions apply to the item of ventilation.

Heating is another question to be given consideration in comparing the relative advantages of the two types of buildings. In a Multistory type the heating expense is slightly less.

Determining Type

Before a final selection of a type of building a group of factors of the relative advantages, and the reasons dictating, the types of construction should be carefully evaluated.[1]

Following is a list of factors indicating and the advantages of a Single Story building:

1. Low cost of ground.

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[1]J. P. Alford and J. R. Bangs, Production Handbook, pp. 730-731.

2. Availability of land for expansion.

3. Less time to build.

4. Less internal area lost.

5. High floor loads.

6. Greater flexibility.

7. Greater efficiency in material handling equipment.

8. Less supervision.

9. Maximum use of natural daylight and ventilation.

10. Occupations easily isolated.

11. Lower operating costs.

The factors indicating and the advantage of Multistory buildings are:

1. High land cost.

2. Limited expansion in area site.

3. Ease of expansion if planned.

4. Limited need for high floor load.

5. Product and equipment light in weight with little bulk.

6. Gravity flow may be utilized.

7. Less dirt.

8. Better lighting and ventilating on upper floors.

9. Lower heat loss through roof.

CHAPTER XI

STANDARD BUILDINGS

The keynote of modern industrial progress is standardization. This principle has been adapted to the construction industry, reducing production costs by the production of pre-fab standardized steel buildings.

These standardized steel buildings have been widespread acceptance due to their meeting exact requirements, to their fire protection, to the ease and speed of erection, to the versatility in enlargement, dismantling and re-erection, to the low annual maintenance cost, and to the economical cost.

Masonry work for installation of standardized steel buildings can most economically be handled through local contractors due to the many physical conditions surrounding this class of work.[1] Roofs can be installed to maintain almost any desired working temperatures.

When standardized steel buildings are purchased delays and expense of dealing with several unrelated sources of supply are avoided. Often there is additional savings in handling and freight charges.

Buildings of this type are furnished by companies such as the Truscon Steel Company, the Blaw-Knox Company, and the Austin Company.

Figure 11-1 illustrates some of the types of standardized steel buildings. The following is the descriptions of various types of the standard buildings produced by the Blaw-Knox Company:

1. TYPE "A" Handy House - An all steel building designed to give maximum strength to structure by means of interlocking joints of steel. Side walls and roof of copper-bearing galvanized sheet steel with especially pressed reinforcing rib. Pitch of roof 1/5 - Height 8' - Widths 4'-6'-8'-10'-12'-14'.

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[1] Blaw-Knox Catalog No. 1535, p. 3.

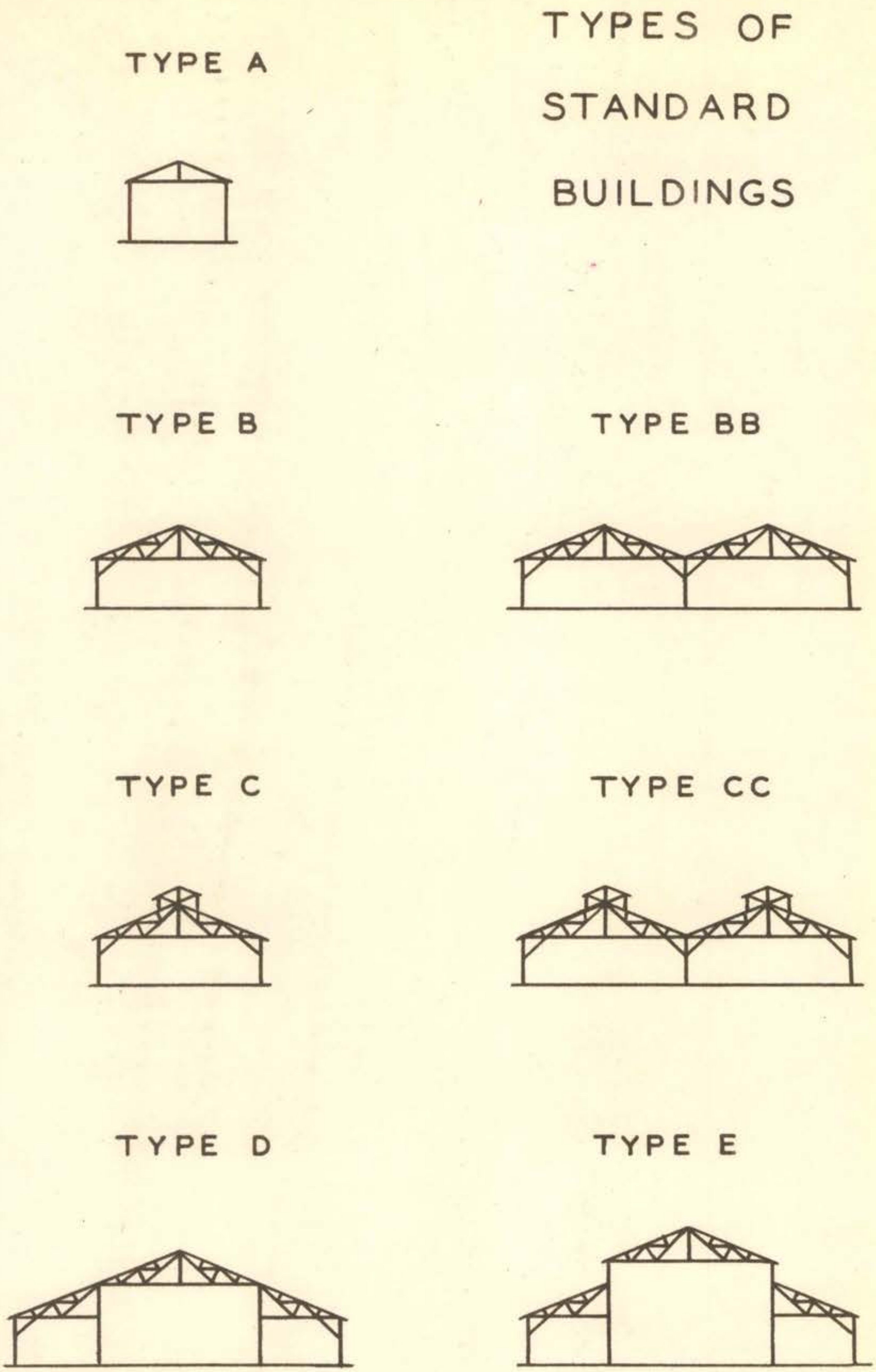

TYPES OF
STANDARD
BUILDINGS
TYPE A
TYPE B
TYPE BB
TYPE C
TYPE CC
TYPE D
TYPE E

Figure 11-1

2. TYPE "B" Clear Span Type - The structural steel frame is furnished in bay lengths of 10' up to and including buildings of 30' in width. Buildings 40' to 100' in width have bays 20' long. The structural frame is of standard rolled sections and the sheet metal covering is copper-bearing galvanized sheet steel. Pitch of roof 1/5 - Heights 8'-10'-12'-16' for Buildings 16'-30' Wide - Heights 12'-16'-20' for Buildings 40' to 100' Wide - Approximate Widths 16'-18'-20'-22'-24'-26'-28'-30'-40'-50'-60'-70'-80'-90'-100'. This type building can be furnished in any length desired in multiples of 2'.

3. TYPE "B-B: Simple Multiple Type - For buildings of greater width than supplied in the clear span types and where center columns are not objectionable this type is very economical. Specifications are the same as for Type "B". Valley gutter and downspouts are furnished. Pitch of roof 1/5 - Heights 12'-16'-20' - Approximate Unit Widths 40'-50'-60'.

4. TYPE "C" Monitor Type - This type is admirable for foundry use or for use where the maximum ventilation is desirable. Specifications for structural and sheet steel are the same as for Type "B". Monitor has continuous ventilating steel sash. Pitch of roof 1/5 - Heights 8'-10'-12'-16'-20' for Buildings 28'-30' Wide - Heights 12'-16'-20' for Buildings 40' to 100' Wide - Approximate Widths 28'-30'-40'-50'-60'-70'-80'-90'-100'.

5. TYPE "C-C" Multiple Monitor Type - For buildings where greater width is necessary than can be supplied in Type "C:. This type is a combination of Type "C: buildings with connecting valley gutter and downspouts - Heights 12'-16'-20' - Approximate Unit Widths 40'-50'-60'.

6. TYPE "D" Three Bay Wide Type - For buildings of greater width than supplied in the clear span type and where two rows of columns are not objectionable, columns spaced 20' 0" center to center the length of building. Specifications are same as for Type "B". Pitch of roof 1/5 - Lean-to Heights 12'-16'-20' - Approximate Widths 80'-90'-100'-110'-120'.

7. TYPE "E" Three Bay Wide Monitor Type - For Monitor buildings where greater width is necessary than can be supplied in Type "C". Continuous ventilating steel sash in upper portion of center bay. Specifications same as for Type "B". Pitch of roof 1/5 - Lean-to Heights 12'-16'-20' - Approximate Widths 80'-90'-100'-110'-120'.

Specifications

Specifications as given by the Company on the buildings as listed need be considered when consideration is being given to the selection of a standardized steel building of this type. A summary of these specifications are:

Type "A" Buildings

Type "A" Buildings are limited in width also in height and are framed by maens of special interlocking rafters, cross ties, and brackets to insure stability. Roofing, siding, and equipment are of the same specifications as for buildings "B", "C", "D" AND "E".

Type "B", "C", "D", AND "E" Buildings

Cover - Roofing and siding are made of heavily galvanized copper-bearing steel sheets into which reinforcing ribs are pressed to develop the utmost strength and rigidity. These sheets are joined together by means of standard interlocking cap which allows for expansion and contraction in the metal and provides a joint that remains tight for the life of the building.

The roof cover is securely fastened to the structural frame work by means of special clips thereby eliminating entirely the use of rivets or bolts. This special method of attaching the roof cover eliminates all holes in the roof surface and relieves the roof sheets of the usual source of rust and corrosion around bolt and rivet holes where the base metal is exposed.

The ridge roll is equipped with lead flashing in order to provide a weather tight construction.

The roof joint channels and eave channels are designed in such a manner as to eliminate capillary contraction. This design also provides for ventilation of the joints which increases the life of the building considerably over the average type of construction. It is essential for good construction to ventilate all joints as it is impossible to protect these joints with paint after building is erected.

All sheets are properly cut and fitted in the shop, also the ends of all sheets are completely flashed. Special trim is furnished for eaves, gables, doors, and windows.

Structural Steel - Structural frames consisting of standard rolled sections are designed and fabricated in accordance with the most modern practice and are shop assembled in large sections for easy and economical erection. Structural steel is given one shop coat of good quality paint. The trusses for buildings 24 feet to 30 feet wide inclusive are designed to carry a 2000 pound load at the center panel point in addition to the normal roof load. The trusses for buildings 40 feet to 100 feet wide inclusive are designed to carry a 4000 pound load at the center panel point in addition to the normal roof loading.

Roof Ventilators - Ventilators are properly weathered and flashed to roof by means of lead flashing and equipped with butterfly damper which is manually operated from floor. However, any ventilating system necessary for efficient operation for any industrial purpose can be provided.

Skylights - Skylights are of the fixed type built into a standard roof sheet panel properly weathered, flashed and cemented. Skylights are 2 feet wide by 4 feet long and are built as an integral part of the roof sheet. One quarter inch rough wire glass is furnished with skylights.

Doors - Doors are of the metal clad type of construction consisting of heavy wood frames of good quality wood well seasoned and covered with galvanized sheet metal, properly fitted and weathered. These doors also have galvanized steel panels. The upper panels of all doors can be glazed with glass and the usual specification is 1/4" rough wire. The single hinged doors are equipped with galvanized T-hinges and rim knoblock. The double sliding doors are completely equipped with track, track brackets, hangers, hasp and staple, pulls and the necessary bottom door guides.

Steel Sash - Steel sash are of the commercial factory type with ventilators arranged to suit any particular requirement. The sash is equipped with cam latch and chain or cam latch and stay bar depending upon the sill height of sash. Continuous side wall sash and monitor sash can be equipped with mechanical operator for group operation. The steel sash is given one shop coat of manufacturer's standard paint.

Glass and Putty - Any type of glass can be furnished for steel sash in accordance with purchaser's specifications together with the necessary steel sash putty. Glass size 14" x 20".

CHAPTER XII

THE LAYOUT OF THE PLANT

The provision of work areas which are safe and healthful to employees and the creation of satisfactory operating efficiency are basic considerations in factory planning and layout. Clean and orderly work places have a direct effect on employee relations. Companies having such conditions usually acquire a reputation of being a good place to work. Plants and allied facilities which are planned to meet the needs of the business trend toward low operating costs.

It is usually difficult and costly to make changes in an arrangement after the construction work is under way, or after the installation of the equipment and machinery has begun. Since the installation drawings for lighting, power wiring, drives, ventilation, exhaust, material, handling equipment, process piping, and building changes depend on the approved layout, it is essential to proceed with its preparations as soon as possible. When the layout is well planned, a suitable arrangement results, adequate requirements are met, installation costs are lower, and loss in production is minimized.

Small factory layouts involve essentially the same problems as those of the large plant. There is the same need for, and analysis of, the flow of the work and conditions under which the product is made. The requirements of the employees are similar, and the economics which are available in the large plant can also be had in the small one.

Scale drawings, templates, and models are equally helpful in studying the arrangement with the small factory as with the large one. When contemplated ideas of arrangement of offices, wash rooms, storage rooms, production area, and other needed rooms or areas are laid out on paper well in advance, savings can be made and a more satisfactory and efficient arrangement will result.

Factors Affecting Factory Planning and Layout

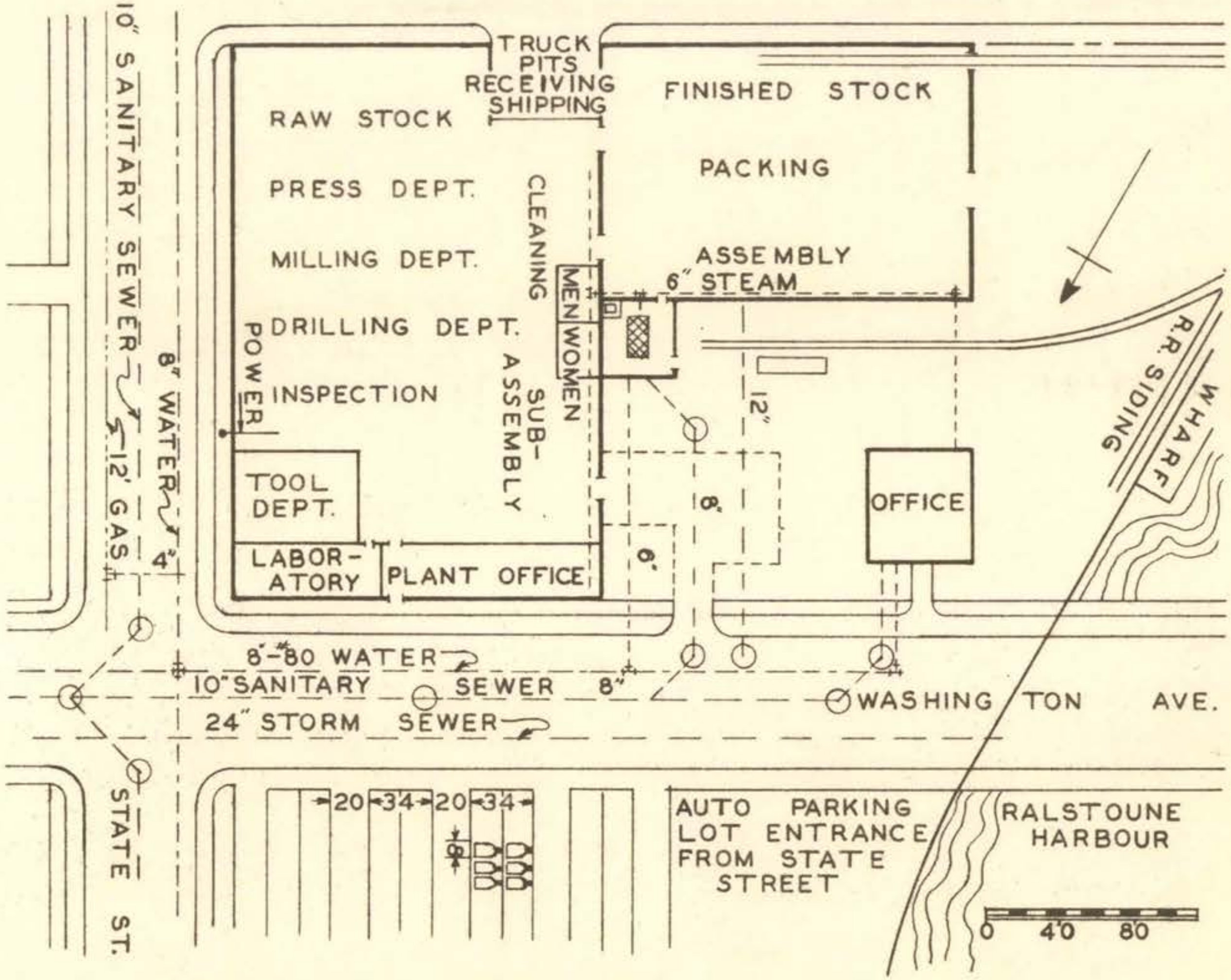
It is well to review the problem from an overall standpoint in order to formulate a background into which the details may be fitted.

First of all, does the problem deal with an existing plant or one that is to be constructed? New buildings can be designed to meet the needs of the processes. Frequently the building itself is but a housing for the production machinery and personnel plus space for auxiliary equipment. If the buildings are already located on the site, it is necessary to fit the equipment and machinery into the available space. In a new factory, there will be periodic changes, expanding or contracting a department here and there.

The relationship of the buildings to the street and to the avenues of approach such as highways, railroads, navigable waterways, and airports should be analyzed. (See Figures 12-1, 12-2 and 12-3).

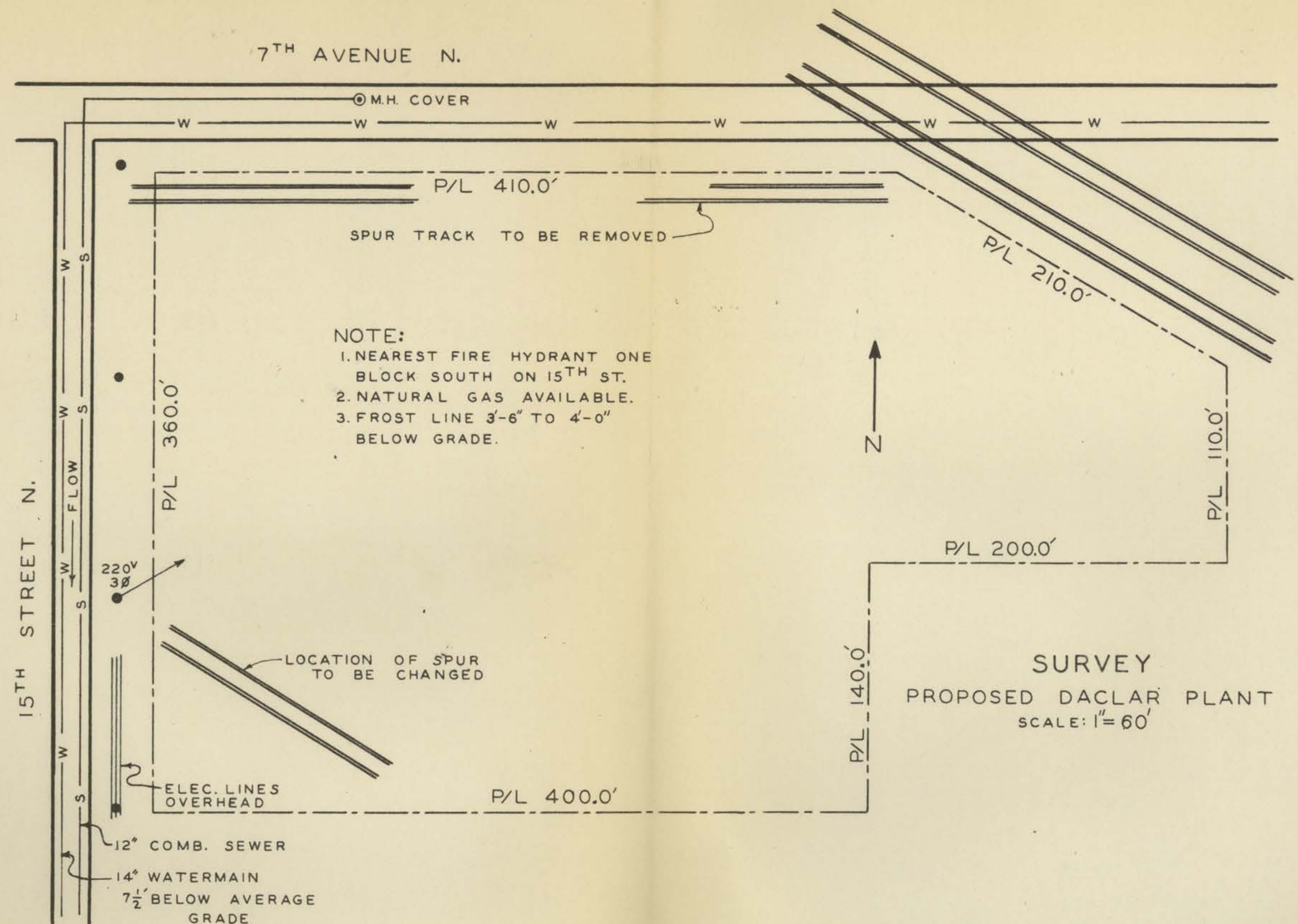
It is essential to know the number and the sex of the people to be employed; availability and location of utilities (gas, water, power, light, sewer, steam, oil, and compressed air); the amount of expansion contemplated and for which products; production routines and sequence of operations; hazards in the industry; and comfort and safety of employees.

When building a new plant or an addition to an existing one, consideration should be given to the type of structure which will best fit the requirements of the business and in many cases how the new structure will coincide with existing structures or buildings in the neighborhood. It is also important to examine the spot on which the new building is to be erected as to soil bearings, rock excavation, grades, fill, and ground water. This is of prime importance, for otherwise an increased cost in conditioning the site and in building design may occur which could be avoided with a more suitable location. The site should preferably be relatively level, at an elevation suitable to the movement



PLOT PLAN

Figure 12-1



7TH AVENUE N.
M.H. COVER
W
P/L 410.0'
SPUR TRACK TO BE REMOVED
P/L 210.0'
NOTE:
1. NEAREST FIRE HYDRANT ONE BLOCK SOUTH ON 15TH ST.
2. NATURAL GAS AVAILABLE.
3. FROST LINE 3'-6" TO 4'-0" BELOW GRADE.
N
P/L 110.0'
P/L 360.0'
15TH STREET N.
FLOW
S
220V 3Ø
P/L 200.0'
LOCATION OF SPUR TO BE CHANGED
P/L 140.0'
SURVEY
PROPOSED DACLAR PLANT
SCALE: 1"= 60'
ELEC. LINES OVERHEAD
P/L 400.0'
12" COMB. SEWER
14" WATERMAIN 7½' BELOW AVERAGE GRADE

Figure 12-2

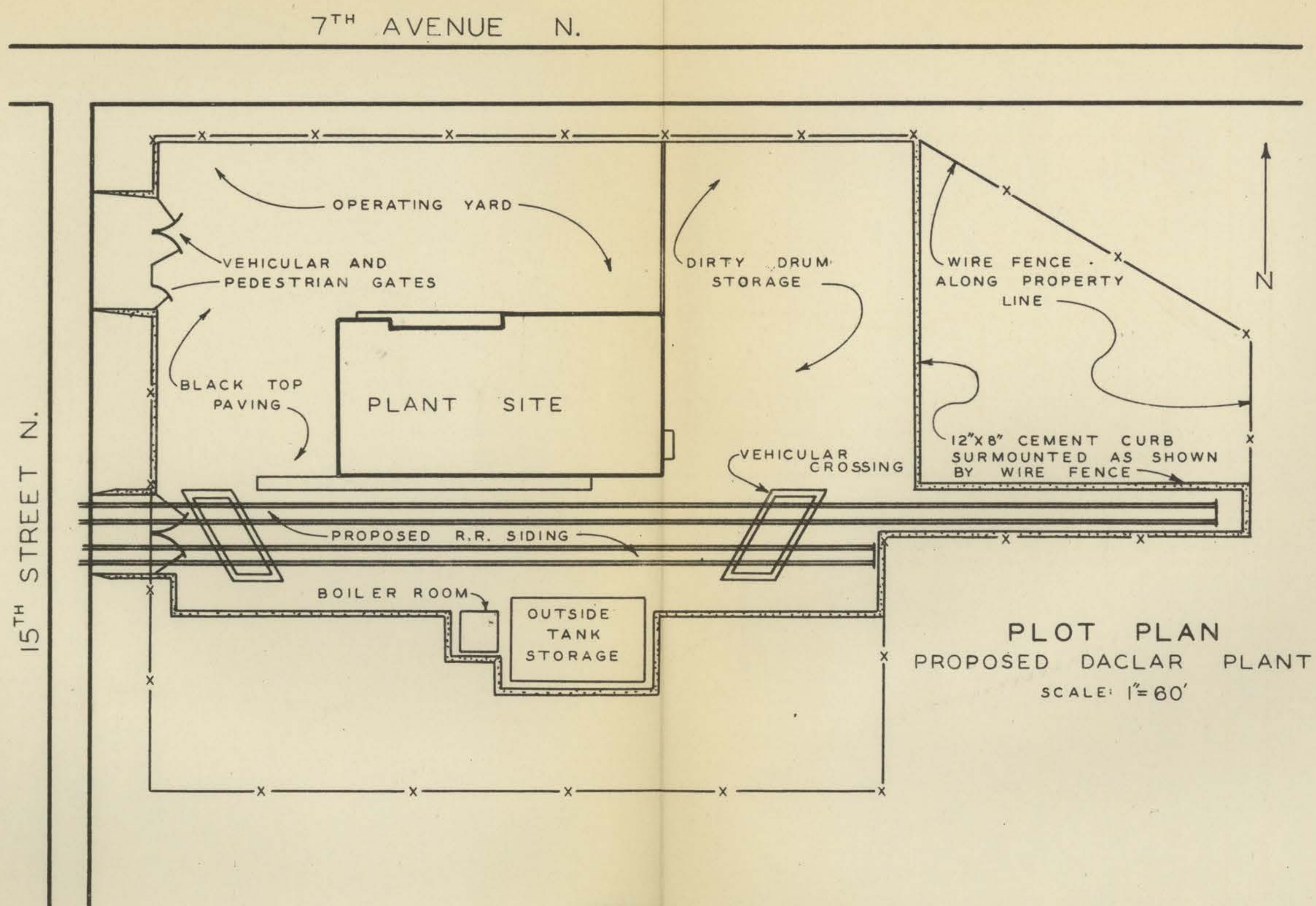

7TH AVENUE N.
15TH STREET N.
OPERATING YARD
VEHICULAR AND PEDESTRIAN GATES
BLACK TOP PAVING
PLANT SITE
DIRTY DRUM STORAGE
WIRE FENCE ALONG PROPERTY LINE
N
12"X8" CEMENT CURB SURMOUNTED AS SHOWN BY WIRE FENCE
VEHICULAR CROSSING
PROPOSED R.R. SIDING
BOILER ROOM
OUTSIDE TANK STORAGE
PLOT PLAN
PROPOSED DACLAR PLANT
SCALE: 1"=60'

Figure 12-3

of materials in and out of the plant, and with sufficient room for expansion and landscaping. Provision for the parking of employees' cars is also essential.

Before the layout is made, it is necessary to review the manufacturing processes and the manner in which the work is being carried on; how the work of one department is related to that of another; the sequence in which the work flows; the amount of material handled and by what means; the number and type of machines and equipment used; and what the future requirements may be.

It is also essential to discern what provisions are necessary to meet the requirements for auxiliary departments such as general and production offices, foremen's offices, storage rooms, shipping and receiving facilities, lunchrooms, washrooms, locker rooms, first-aid room, entrances and exits for the arrival and departure of employees, engineering departments, and nonproduction and maintenance shops. When insufficient thought is given to these essentials, the new layout is likely to contain features which contribute to loss of time on the part of employees and needless cost in the handling of materials. Thus, working conditions may be created which retard production and cause discomfort to employees. Then, too, there are also certain processes constituting hazards which require special study. It is essential to have an arrangement which facilitates supervision of the work. In general, conditions are sought which will contribute to modernization, flexibility, high employee morale, and plant efficiency.

A layout drawn to a scale of 8 feet to the inch (1/8" = 1') has been found convenient, for it is sufficiently large to show the detail for installation purposes and yet not too large to view departments covering large areas. Then, too, it is easy to scale with an ordinary rule. It may be difficult, however, to present sufficient detail required in intricate processes. A scale of 4 feet to the inch (1/4" = 1') and sometimes a larger scale is preferred for this. A scale of 1/16" to the foot is also used for making over-all presentations of very large plants. When conditions require it, drawings which are made in one scale can be reduced or increased in size by photographic process. Illustrations are shown in Figures 12-4 and 12-5. Such scale as 1" = 100' and 1" = 40' which are used for maps are easy to scale with an ordinary rule.

Profiles showing the variation in the elevation of the land and topographic maps are useful for establishing floor levels. Cross sections and elevations of the buildings are helpful for studying the movement of materials, ventilation problems, light conditions, and head room. These are usually drawn on the same scale as the layouts.

Data Needed

A listing of all the departments to be accommodated is the first step. When these are arranged in alphabetical sequence, they are helpful for reference and checking purposes. The next step is to obtain a tabulation of the personnel by departments, both as to men and women, as shown in Figure 12-6. The information concerning the personnel is needed in order to have criteria from which to provide suitable facilities for employees as referred to earlier in this chapter.

Machinery and equipment schedules are prepared which contain machine reference number, location (department, building, floor), machine description, and quantity. All of this information is helpful in calculating the areas required for manufacturing, determining the amount and kind of power, checking floor loads, and answering questions relating to equipment foundations, floor construction, ceiling clearances, drains, piping, ventilation, drives, conveyors, and the disposition of waste materials. A suggested form is shown in Figure 12-7.

The process charts and flow diagrams are very useful for the following

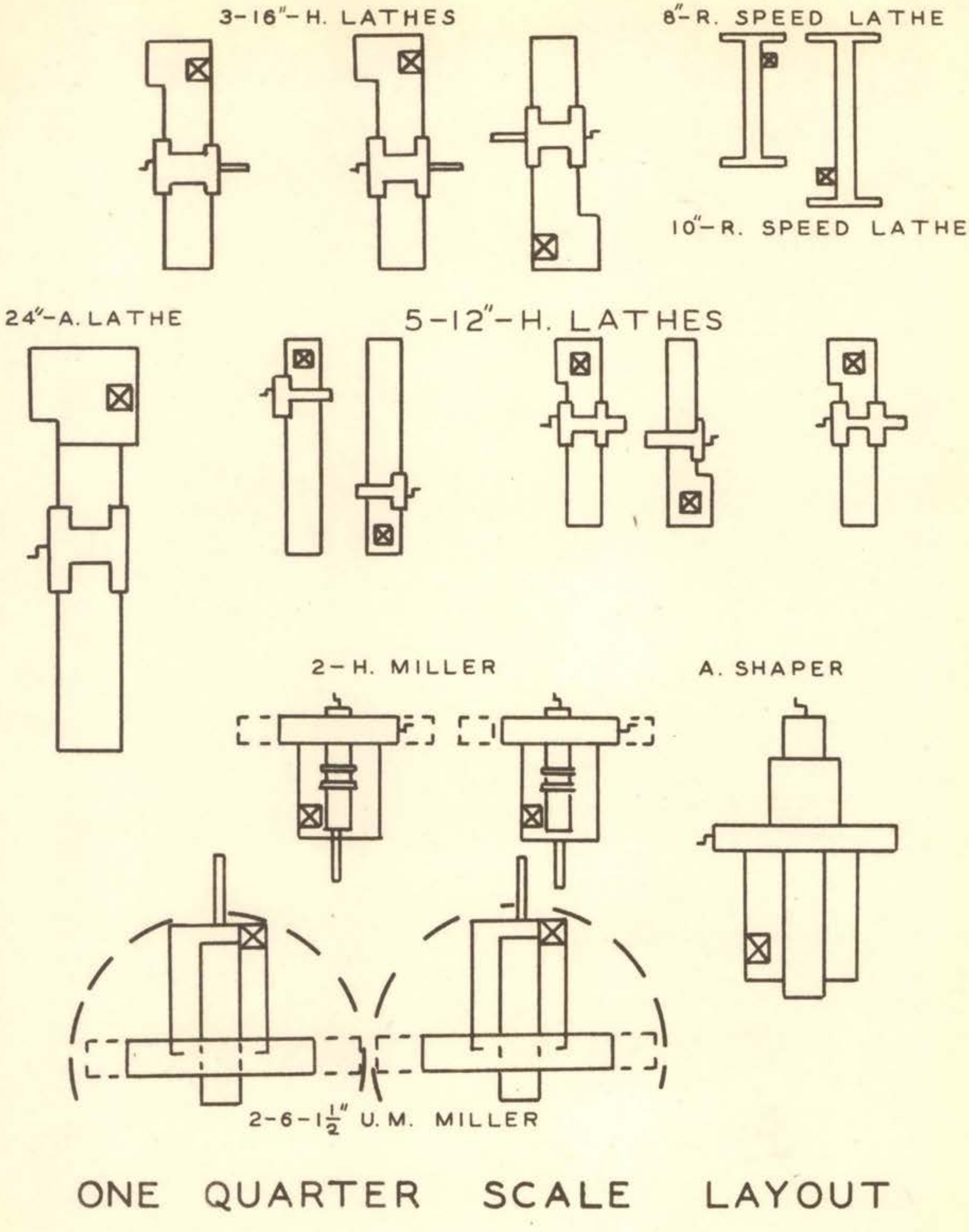

3-16"-H. LATHES
8"-R. SPEED LATHE
10"-R. SPEED LATHE
24"-A. LATHE
5-12"-H. LATHES
2-H. MILLER
A. SHAPER
2-6-1½" U.M. MILLER
ONE QUARTER SCALE LAYOUT

Figure 12-4

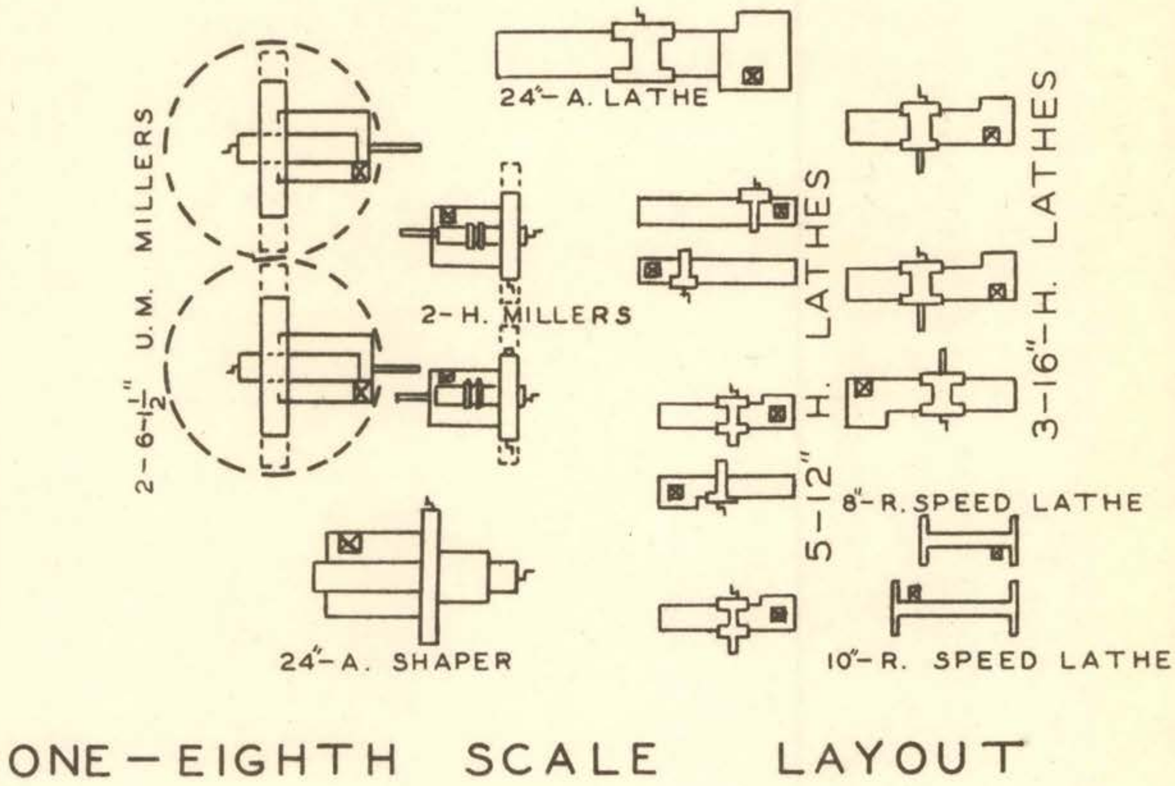

24"- A. LATHE
2-6-1½" U.M. MILLERS
2- H. MILLERS
5-12" H. LATHES
3-16"-H. LATHES
8"-R. SPEED LATHE
24"-A. SHAPER
10"-R. SPEED LATHE
ONE-EIGHTH SCALE LAYOUT

Figure 12-5

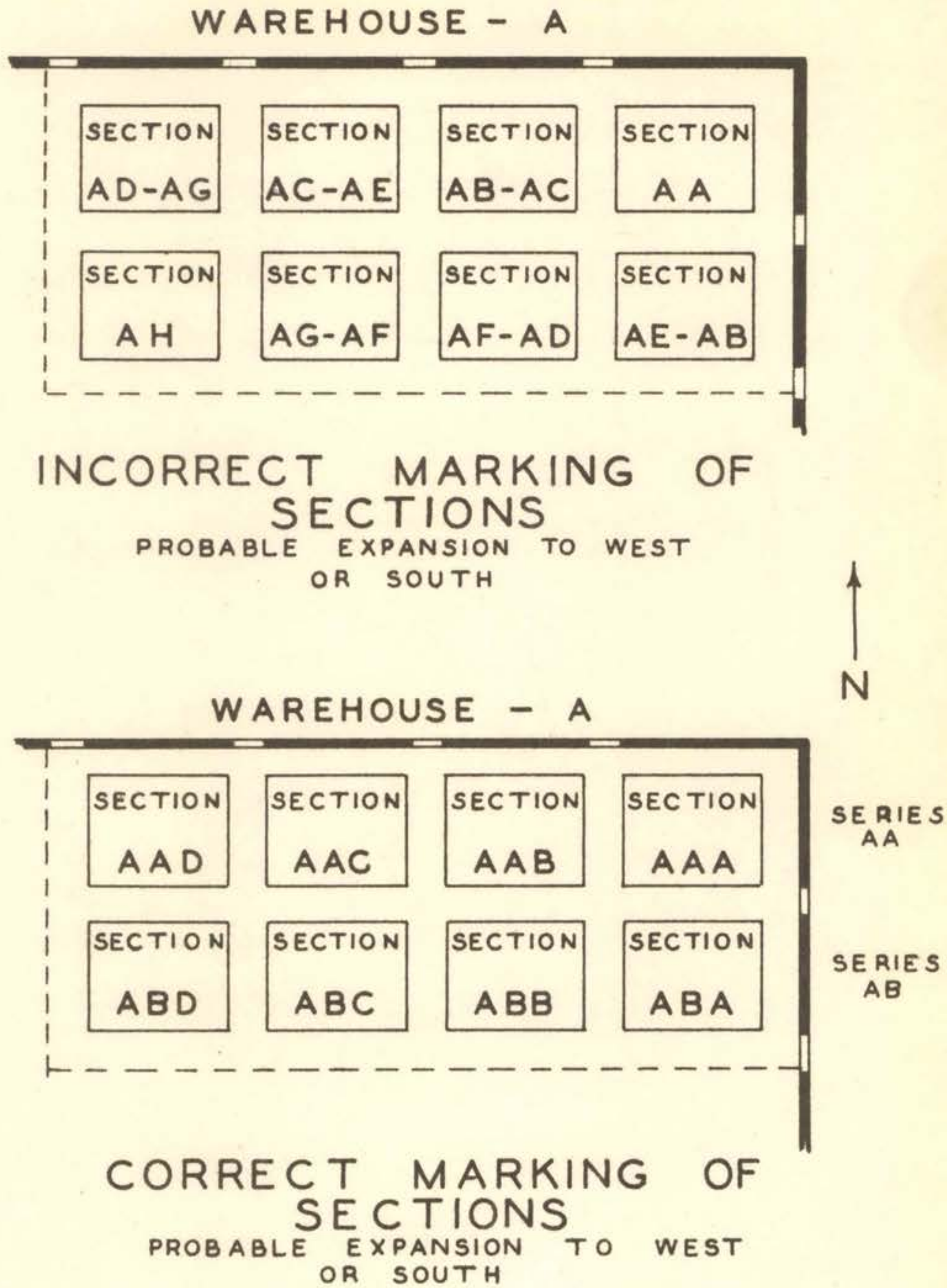

WAREHOUSE - A
SECTION AD-AG
SECTION AC-AE
SECTION AB-AC
SECTION AA
SECTION AH
SECTION AG-AF
SECTION AF-AD
SECTION AE-AB
INCORRECT MARKING OF SECTIONS
PROBABLE EXPANSION TO WEST OR SOUTH
N
WAREHOUSE - A
SECTION AAD
SECTION AAC
SECTION AAB
SECTION AAA
SERIES AA
SECTION ABD
SECTION ABC
SECTION ABB
SECTION ABA
SERIES AB
CORRECT MARKING OF SECTIONS
PROBABLE EXPANSION TO WEST OR SOUTH

Figure 7-5

Tabulation of Personnel

General Departments	No. of Men	No. of Women	Total	Factory Departments	No. of Men	No. of Women	Total
Engineering	-	-	-	Bench	-	-	-
First Aid	-	-	-	Drill	-	-	-
Lunchrooms	-	-	-	Grinding	-	-	-
Maintenance	-	-	-	Inspection	-	-	-
Office	-	-	-	Press	-	-	-
Personnel	-	-	-	Receiving	-	-	-
Production Control	-	-	-	Shipping	-	-	-
Protection	-	-	-	Stock Room	-	-	-
Research	-	-	-	Supervisors Office	-	-	-
Standards and Methods	-	-	-	Tool Crib	-	-	-
Steam Plant	-	-	-	Toolroom	-	-	-
Transportation	-	-	-	Warehouses	-	-	-
etc.	-	-	-	etc.	-	-	-
Total	-	-	-		-	-	-

(For day shift only)

	Men	Women	Total
Grand Total--	-	-	-
Percentage	-	-	-

Figure 12-6

Machinery and Equipment Schedule

Reference Number	Department	Building Number	Floor	Machine Description (M = Motor Drive)	Quantity
295	Milling	1A	1	B. & S. No. 12 Miller (M)	1
296	"	1A	1	Cinn. No. 1-18 Miller	1
---	-------	--	-	------------------------	-
---	-------	--	-	------------------------	-
654	Press	2B	1	Bliss No. 73A - P.P. (M)	1
655	"	2B	1	Standard No. 93-P.P.	1
---	-----	--	-	------------------------	-

Reference numbers may be identification symbols which are usually attached to the equipment for insurance or production purposes. At other times the reference numbers are a numerical sequence used for making the study. When listing machines by departments it is well to have all the machines in the same department grouped together. With machine descriptions it is helpful to designate the make, size, and kind, and to have the same type of machines within the department listed together.

Figure 12-7

purposes: (1) to visualize how the work of one department ties into that of another, (2) to indicate the amount of material moved from one department to another and the order in which it is moved, (3) to determine the degree to which individual departments are self-contained, and (4) to show those departments which are service units. The flow diagrams are also useful when developing department relation diagrams which are used for incorporating into the layout those departments that would be best located adjacent to each other. (See Figure 12-8).

Space Requirements

For preliminary studies and the designation of department areas, factory space requirements may be stated in terms of square feet per department or section. This is usually tabulated in the form shown in Figure 12-9. Departments are listed in alphabetical order as in Figure 12-6. Those departments in which more than one major task is performed should show the breakdown by operations, such for example as the following:

Press Department

Press work
Tool crib
Work-in-process
Bar stock
Strip stock
Roll stock

Figure 12-9 provides a convenient manner for a summarization and contains sufficient detail to identify related items. A clearer picture of the economical utilization of space is had when the miscellaneous items are set apart from those needed for manufacturing purposes.

Factors which affect the space needed include the following:

1. Nature of the available space - In the manufacture of many products, large open space with wide column spacing, in Single Story or Multistory buildings, is preferable to small and irregularly shaped areas. With the former, a flexibility is afforded in the manner of layout. It is

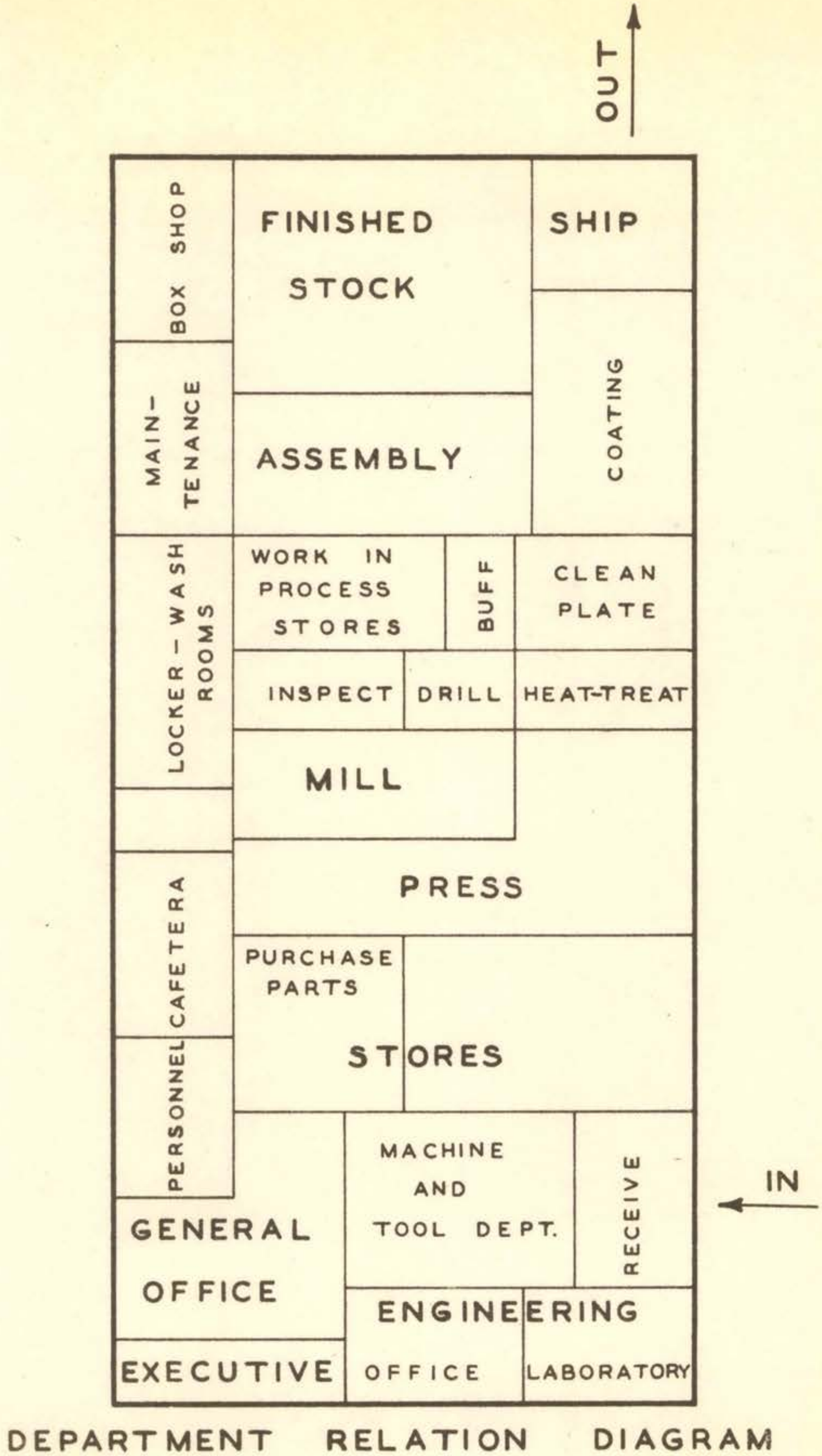

OUT
BOX SHOP
FINISHED STOCK
SHIP
MAIN-TENANCE
ASSEMBLY
COATING
LOCKER – WASH ROOMS
WORK IN PROCESS STORES
BUFF
CLEAN PLATE
INSPECT
DRILL
HEAT-TREAT
MILL
PRESS
CAFETERA
PERSONNEL
PURCHASE PARTS
STORES
MACHINE AND TOOL DEPT.
RECEIVE
IN
GENERAL OFFICE
ENGINEERING
EXECUTIVE
OFFICE
LABORATORY
DEPARTMENT RELATION DIAGRAM

Figure 12-8

Space Requirements

Department	Operation	Required Area	Scheme I	Scheme II
Bench	Burr	1,200 sq. ft.	1,300 sq. ft.	1,140 sq. ft.
Drill	Drilling	2,500 sq. ft.	2,600 sq. ft.	2,100 sq. ft.
-----	---------------	------------	------------	------------
-----	---------------	------------	------------	------------
Press				
"	Press Work	4,800 sq. ft.	4,900 sq. ft.	4,700 sq. ft.
"	Tool Crib	1,200 sq. ft.	1,300 sq. ft.	1,200 sq. ft.
"	Work-in-process	1,500 sq. ft.	1,600 sq. ft.	1,400 sq. ft.
-----	---------------	------------	------------	------------
Receiving	---------------	1,600 sq. ft.	1,750 sq. ft.	1,500 sq. ft.
Total		-----	-----	-----
Miscellaneous				
Aisles, ramps				
Columns, walls				
Wash and locker rooms		3,000 sq. ft.	3,100 sq. ft	2,900 sq. ft.
Elevators and stairs		500 sq. ft.	500 sq. ft.	500 sq. ft.
Total		-----	-----	-----
Grand Total sq. ft.		-----	-----	-----

This type of tabulation provides a convenient manner for a summarization and contains sufficient detail to identify related items. A clearer picture of the economical utilization of space is had when the miscellaneous items are set apart from those used for manufacturing purposes, as shown above.

Figure 12-9

favorable to good working conditions and has advantages in the movement of materials and in ease of supervision.

2. Product manufactured - The space requirements for any given machine will vary according to the industry. The amount of space needed for the storage of raw materials and finished products, work-in-process areas, aisle widths, work space around machine, and warehousing will also vary. The extent to which gravity flow enters into the process affects the space requirements and has a bearing on the type of building needed

Computing Area Requirements

Based on the factors mentioned above, the approximate areas required can be computed by assigning area values to each machine or piece of equipment and then adding up the total of these plus an allowance for aisles, work space, and expansion.

Allocation of Area

After the departmental areas have been established, with due allowance for expansion, the next step is to allocate the area needed for each department to its logical place in the new layout.

When allocating the areas, it is helpful to have knowledge of the following:

1. The manner of receipt and delivery of goods into and out of the plant.

2. The relationship between departments, both manufacturing and general.

3. Methods of handling materials between operations within the same or other departments.

4. Processes requiring special plumbing facilities. For example: acid drains or treatment equipment for the disposal of factory waste which is prohibited by ordinance or by expediency from being dumped in the sanitary sewer system or into streams. Provisions for these installations, if needed, should be made.

5. The departments and sections in which large numbers of people work close together.

6. The departments and sections in which particularly good

light is essential. Is natural light available, or will special artificial illumination be required?

7. Places where work-in-process and storage areas are needed so as to hold the work between operations and minimize the handling. Main aisles suitable for the movement of material through the plant and for the safety of employees.

8. Situations where long-term savings can be made, either in greater length of life or in lower repair costs, by making high-quality installations at an increased initial outlay. The greater initial cost may be offset by lower operating cost. This, however, may not apply to equipment having a high obsolescence rate or where the need for the product does not recur regularly.

9. Instances where small service machines could be provided so as to obviate the necessity of sending components to other departments to have minor operations performed.

10. Floor-load requirements. It may be necessary to locate certain large and heavy machines on the group floor; otherwise the cost of reinforcing would be excessive.

11. Processes which require special treatment can often be located adjacent to each other and so effect economies in installation.

Rough Layout

The preparation of the layout involves three steps:

1. Obtaining a floor plan of the space to be occupied.

2. Preparation of templates or models.

3. Arrangement of the templates or models on the floor plan.

Floor Plan

Preliminary or outline drawings of the proposed plant will serve as a background into which the layout may be fitted.

Templates

A template is prepared for each machine or piece of equipment drawn to the same scale as is used for the floor plans. Two forms of templates are in use: the block and the two dimensional. The former indicates the base area occupied by the machine (usually in rectangular form); the latter shows the outline of the machine in detail, including travel of moving parts, together with drive, work stands, tote boxes, trucks, and other equipment. Separate colors are often used for differentiating between various types of equipment. Color schemes are also used to note the different departments. It is frequently necessary to select colors which will photograph differently. Colors which produce different shades when reproduced are salmon, fawn, yellow, green, and cherry.

Models of the machinery and equipment, made to the same scale as the drawings, are also used. These have the advantage over templates of presenting objects in the third dimension.

A rubber base or nonhardening cement is commonly used for attaching templates or models to the floor plan. The templates can be taken off easily or moved from place to place as changes in the layout are made.

Arranging Machinery

Careful consideration should be given when laying out a department to the question of whether to use an arrangement which follows the sequence of operations, in the case of production shops, and one which follows the grouping of machines by classes of work in the jobbing shop; and oftentimes a combination of these will produce a satisfactory layout.

The first arrangement mentioned is called product arrangement, straight-line, or unit production arrangement. Machines and work stations are arranged in proper sequence to give a minimum amount of handling between successive operations. This type layout has the following advantages: handling and moving of materials are reduced; less volume of work is in process, there is a saving of time in process; production planning and scheduling problems are simplified; there is less inspection, counting, and clerical work; and it requires less flow space.

The second arrangement mentioned is called functional arrangement. The work is moved from one department or machine group to another in going through the process. The advantages of this type layout are a high degree of flexibility in use of equipment, maximum machine activity and usefulness, a high degree of efficiency by supervisors and operators, and less maintenance expense.

Material Handling

Material handling devices cover a range all the way from the simple trays and tote boxes to the skids, pallets, trucks, roller conveyors, moving platforms and pneumatic tubes. When properly selected, these can simplify the handling required and reduce costs.

Aisles and Work-In-Process Areas

In making the layout, adequate work-in-process areas and aisles for the movement and storage of materials, which are waiting between operations as they flow through the plant, must be provided.

It is also advisable to allocate sufficient space at the machines to maintain work far enough ahead so that the operator is not called upon to seek materials too often. Then, too, allowances need to be made for the workstands, scrap boxes, die and tool racks, pallets, and stools and for space the workmen require in operating the machines.

Finished Layout

The final layout will result in a compromise between the idea and the numerous conditions which are inherent in the whole problem balanced against the cost, the manufacturing efficiency, and the desired standards of working conditions.

Plant Layout Check List[1]

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[1] Standards and Plant Layout, p. 27.

1. Is back-tracking at a minimum?
2. Is natural light use at a maximum?
3. Is there a logical departmental arrangement?
4. Are department and service areas centrally located?
5. Is material storage space adequate?
6. Are stock racks provided where necessary?
7. Is aisle space adequate and logically located?
8. Are exits located properly?
9. Are departments working on heavy parts located near shipping and receiving departments?
10. Do sub-assembly lines end at main assembly lines?
11. Is the shipping department at the end of the final assembly line?
12. Is material handling equipment used where practical?
13. Are machines properly spaced?
14. Is service area around machines adequate?
15. Does plant present a crowded appearance?
16. Are there any long moves?
17. Is there too much material handling equipment?
18. Are any pieces of equipment "locked-in"?
19. Is there too much storage space?
20. Has proper allowance been made for:
    a. Maintenance area.
    b. Tool crib.
    c. Lockers.
    d. Lavatory.
    e. Eating area.
    f. Office space.

g. Fire extinguishers.

h. Drinking fountains.

i. Storage area.

j. Operators.

k. Flow lines.

l. Receiving department.

m. Shipping department.

n. First aid station.

o. Inspection facilities.

CHAPTER XIII

HEATING AND VENTILATING

In the selection of heating and ventilation of any building, the decision of system to be used depends upon two factors: (1) the requirements desired for heating and ventilating and (2) the building type and construction. The requirements may depend upon the comfort, health, and efficiency of the persons within the required area, or the requirements may depend upon the process involved. Certain systems will be economically practical when placed in definite types of buildings. The construction of the building will determine the economic cost of the system and will determine heat losses. Knowing the requirements desired and the building for the installation the system can be selected and the design made.

Requirements

When the requirements depend upon personal comfort, the physiology of the human body must be considered. The human body is at all times losing heat and at the same time heat is being formed by oxidation within the body. The body temperature is regulated in two ways by regulation of internal heat production, or chemical regulation, and regulation of heat loss by means of automatic variation in the rate of cutaneous circulation and the operation of the sweat glands. The body normally responds to the environment with complete regulation. That is when the environment is less in temperature than body temperature, the body responds by decreasing the rate of cutaneous circulation and decreasing the amount of moisture thus holding the heat within the body. Hence, the major objective of heating and ventilating is to balance heat losses from the human body of which the basic factor is metabolism.

The four basic factors in the control of comfort and human health would be:[1]

1. Air Temperature (free from radiation effects).

2. Air Movement.

3. Humidity.

4. Mean radiant temperature of surrounding surfaces.

For the normally vigorous persons, normally clothed, and at rest, an air temperature of 65° F. should be provided at knee-height, eighteen inches, in order to prevent chilling of the legs and feet. Generally this will correspond to an air temperature of 70° F. at a height of five feet. The air temperature may be increased or decreased to compensate for deviations of mean radiant temperature above or below air temperature and according to the age of the occupants.

Air movement has a powerful influence on the factors involved in thermal equilibrium of the body. An understanding of the phenomena involved is best obtained through consideration of the purely physical factors involved in the effect of air movement on heat dissipation from inanimate surfaces by radiation, convection, and evaporation. Radiation loss has no change unless there is a change in the skin surface temperature. Convection loss is greatly increased by air movement, provided the surface temperature remains the same. Heat loss by evaporation is greatly increased by air movement, provided surface temperature is higher than the air and moisture is available for evaporation. However, since in the human body perspiration is only made available when there is need for increased evaporative heat loss due to reduction in convection loss, increased air movement is accompanied by decreased perspiration and evaporative cooling in moderately cool atmospheres. In very hot atmospheres, particularly

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[1] J. R. Allen, J. H. Walker, and J. W. James, Heating and Air Conditioning, pp. 338-339.

with low vapor pressure, evaporative cooling may be increased by air movement so as to increase the maximum temperature level at which thermal equilibrium may be maintained.

Air movement should never have a velocity so there is produced an objectionable draft due to uneven cooling of the body surface. During the heating season air velocities in excess of 25 to 30 feet per minute usually give undesirable effects.[2] With summer cooling and air conditioning higher velocities up to 40 or 50 feet per minute, if properly controlled, seem to give satisfactory conditions free from sensations of draft.[3]

In any enclosed building it is desirable to introduce outside air for the comfort of the occupants. The amount of fresh air needed will depend upon the activity performed and other factors. The following may be used as a guide in calculating the fresh air desired under given circumstances:[4]

Location	Amount of Outdoor Air in Cubic Feet per Minute Per Person
1. Auditoriums - spaces where "No Smoking".	5 to 7.5
2. Open Spaces - banks and general buildings.	7.5 to 10
3. Hospital Rooms - open spaces in general offices; restaurants and public dining rooms.	10 to 15
4. Director's Rooms - private offices; spaces where there is heavy smoking.	20 to 30

The most comfortable range of humidity has not yet been determined. The experiments show that a majority of the subjects were unable to detect sensations

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[2]Lionel S. Marks, Mechanical Engineer's Handbook, p. 1660.

[3]Marks, loc. cit.

[4]L. P. Alford and J. R. Bangs, Production Handbook, p. 821

of humidity when the relative humidity was between 30 percent and 60 percent with ordinary room temperatures.[5] Experiments also have shown respiratory membranes of industrial workers exposed to hot moist air are distinctly abnormal compared with those of workers exposed to hot dry air.

The effective temperature differs for people of different climates and between the sexes. By experiment, effective temperature is the arbitrary index which combines in a single value the degree of warmth or cold felt by the human body in response to the air temperature, moisture content, and air motion. Charts have been made for easy reading for: (1) comfort in still air; (2) relation between total heat loss from the human body and effective temperature for still air; (3) relation between sensible heat loss from the human body and dry-bulb temperature for still air; (4) relation between latent heat and moisture loss from the human by evaporation and dry-bulb temperature for still air conditions; (5) relation between heat loss from the human body by evaporation, radiation, and convection and dry-bulb temperature for still air conditions; and (6) for the thermometric or effective temperature chart. These charts are found in the Heating, Ventilating, Air Conditioning Guide.

These charts are used to determine the feeling of comfort and healthful conditions by determining the effective temperature, the amount of heat and moisture losses from the human body. Where the occupants are few and scattered, the effect of body heat is not so important. Where occupants are closely congregated, the removal of the excess heat and water vapor produced by the human body presents a problem. If the temperature of such a space is correctly adjusted when the occupants enter, it will rise steadily during the period of occupancy as a result of heat given off by the occupants. In a room containing

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[5] Heating, Ventilating, Air Conditiong Guide of 1948, p. 212.

many persons the effects of the body heat can be neutralized by admission of outside air without producing unpleasant and dangerous drafts on those near the windows or other inlets. The supply of air before it reaches the occupant should be so tempered as to avoid drafts but in an amount and at a temperature which will remove the sensible heat produced by metabolism. With no heat loss through walls this will require 28 cubic feet per minute of air per person when admitted at 60° F. and at an average temperature of 78° F. for air leaving the room.[6] With crowded rooms, and with any rooms containing 50 or more occupants forced ventilation will be essential.

Metabolism and uncomfortable drafts are but two of the essentials to health of the occupant. Expired air may be odorous, offensive, and capable of producing loss of appetite and a disinclination for physical activity. Objectionable body odors have the same effect. In certain industrial processes toxic fumes and gases may be produced whose removal by local exhaust ventilation is essential for the protection of human health.

From the standpoint of health, comfort, and efficiency, the Philadelphia Electric Company found that lost time due to colds and similar disorders decreased 33 percent and 46 percent in the first and second years, respectively, after the installation of complete air conditioning. In the Drafting and Surveying Bureau of the Detroit Edison Company, a 51.4 percent increase in efficiency was largely attributed to air conditioning. Plant efficiency may be gained from complete air conditioning by the following points:[7]

1. Lower manufacturing costs.
2. Improve quality of product.

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[6] _Ibid._, p. 222.

[7] Alford and Bangs, _op. cit._, p. 819

3. Protection of goods in storage.

4. Improved health of employees.

5. Improved comfort and efficiency of employees.

Industrial air conditioning is primarily concerned with atmospheric conditions required for the manufacturing, processing, and preservation of material, equipment, and commodities. The fundamental factors, one or more of which may govern these conditions are: (1) humidity, (2) temperature, (3) air motion, and (4) air purity. The term air purity may have reference to the quantity of dust, soot, bacteria, odors, or toxic gases present.

The most desirable relative humidity for processing depends upon the product and the nature of the process. As far as the behavior of the material and its desired final condition are concerned, each material and process presents a different problem. The desirable relative humidity may range from a low of 5 percent, as in certain industrial application, such as insulation widing processing, up to a condition approaching saturation, as in processes relating to textiles, tobacco, and baking industries.

It is generally recognized that relative humidities of 50 percent or less are on the dry side. Such conditions are conducive of low regains in hygroscopic materials, drying out, increased brittleness of fibrous materials, prevalence of increased static electricity and tendencies toward increased dust liberation from the product. Relative humidities higher than 50 percent are considered to be on the damp side. These conditions are conducive to high regain, promote softness and pliability in materials, decreases static electricity and tendencies toward reduced generation, or produce dust which represents a loss in weight and of the material in process.

In many processes, the optimum desired air conditions are variable according to the stage and progress of the processing cycle, from the raw to the finished product. Some materials, such as cotton textiles, begin with a low relative humidity in the carding and picking rooms, and after passing through the various intermediate steps with a gradual increase of relative humidity, the product is subjected to relative humidity of 75 percent to 85 percent in the final stage of weaving. Other processes are encountered that require the reverse of this procedure, starting with a high relative humidity and finishing with a low relative humidity, as is the case when producing glue and gelatinous materials and making gelatine capsules.

Similarly, the most favorable temperature will vary according to the specific material and particular process. Frequently a compromise between the known optimum condition for processing and that required for reasonable worker comfort is desirable. This is particularly true where unconfined processes are required in departments where people are working and their health, comfort, and productive efficiency must be considered.

In a plant where the process or the product does not require special consideration, the following may be used as a guide in establishing the requirements for comfort:

Kind of Building and Room	Temperature Degree F.
1. Bathrooms.	85
2. Boiler shops.	50 - 60
3. Clothing shops.	70
4. Factories (General).	65
5. Foundries.	50 - 60
6. Hospitals.	72 - 75
7. Machine shops.	60 - 65
8. Offices.	70
9. Paint shops.	80

Kind of Building and Room	Temperature Degree F.
10. Shoe Factory.	68 - 72
11. Textile mills.	75 - 80
12. Woodworking shops.	60 - 65

It is well to remember the same feeling of warmth will be experienced from the following conditions: Temperature, 75° F. - Humidity, 60%, and Temperature, 79° F. - Humidity, 30%.[8]

Air conditioning contributes an important role during the processing, machining, and honing of precision metal parts, instruments, tools, engines, and guns, which demand micrometric accuracy of dimensions, and which are affected by small temperature variations. Hence, some uniform condition is usually selected both as to temperature and humidity to serve the demands of the workers' comfort and the exacting requirements of the process.

In the manufacture of interchangeable parts, cost may be decreased by holding close allowances and tolerances uniform with no thermal change at assembly; thus waste is lessened. It may be said that less time will be lost in argument. Cost may be decreased by reduced spoilage and longer storage due to air conditioning. Whole businesses may be allowed to move closer to their supply of raw material because of air conditioning. The relocation in the South of the cotton industry is an example of this.

An example of processing requirements can be shown by the data of the Baking Industry:

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[8] *Ibid.*, p. 820.

	Temperature Degree F.	Relative Humidity %
Cake Icing	70	50
Cake Making	75	65
Dough, fermentation room	78	75 - 80
Dough, retarding	32 - 40	76 - 85
Loaf, cooling	70	60 - 70
Make-up room	75 - 80	55 - 70
Mixing room	75 - 80	55 - 70
Paraffin paper wrapping	70	55
Proof boxes	90 - 95	80 - 90
Storage of flour	65 - 75	55 - 65
Storage of yeast	32 - 45	60 - 75

This data changes with industry.

Building

The type of building which is to be heated and ventilated will be economically determined by the purpose of the building. The building may be multistoried, one-story covering considerable area, or small and compact. The construction of the building may differ from a sheet metal building to a concrete wall lined on the outside with brick and plastered on the inside. It may have from one door to a complete glass wall. Every factor must be considered.

Heat is that form of energy which is transferred from place to place by virtue of an existing temperature difference. Heat will flow from the higher temperature to the lower temperature only and may be disseminated by conduction, convection, and radiation. In respect to building materials the transmission of heat is effected by their character and thickness, their arrangements in the building construction, the temperature difference maintained, their means absolute temperatures, the movement of air over exposed surfaces, and the time interval during which the flow of heat occurs.

The calculation of the heat transmitted by either conduction, convection, or radiation, involves the use of surface temperatures, which are often difficult to obtain. Therefore, a coefficient of heat transmission is desirable which takes into account the effect of conduction, convection, and radiation together with the kind, thickness, and placement of the materials, and which may be used with the difference of the air temperatures existent adjacent to each side of the wall section under consideration. Such a numerical quantity is the over-all coefficient of heat transmission, U, which is defined as the amount of heat, in BTU per hour, transmitted per square foot of area of the material as used per one degree F. of inside and outside air temperature difference.

In equation form the expression of the transmission of heat through the enclosing envelope of a space is:

$$H = UA \ (t - t_o).$$

where:

- H = heat transmitted per hour, BTU.
- U = Over-all coefficient of heat transmission.
- A = area of wall, etc., sq. ft.
- t = inside air temperature, degree F.
- t_o = outside air temperature, degree F.

The over-all coefficient of heat transmission for a wall section may be determined either experimentally or by calculation involving the use of known data from the materials included. Conductance is defined as the amount of heat in BTU per hour passing through on square foot of area of any material of the thickness and arrangement stated, per one degree Fahrenheit difference of the material surface temperature. The coefficient is calculated by dividing the summation of the reciprocals of circumstances into one.

$$U = \frac{1}{\frac{1}{f_i} + \frac{1}{f_o} + \frac{x}{k}}$$

where:

- f_i = combined coefficient of radiation and of warmer wall surface.
- f_o = combined coefficient of radiation and convection of cooler wall surface.
- x = thickness of wall
- k = coefficient of heat conductivity.

The date for coefficients of radiation and convection and those of heat conductivity may be taken from tables and graphs. Other tables will record U for certain walls, doors, roofs, and floors.

When an attic space is unheated a combined coefficient of heat transmission for the roof above and the ceiling area below it may be estimated. This combined coefficient is used with ceiling area and the difference between the temperature of the air below the ceiling and that of the outside air, when calculation of the loss of heat through an attic space are made. The combined coefficient, per square foot of ceiling area, for a ceiling, an attic space, and a roof is:

$$Ucr = \frac{Ur \times Uc}{Ur + \frac{Uc}{r}}$$

where:

Ur = coefficient of heat transmission for the roof.
Uc = coefficient of heat transmission for the ceiling.
r = ratio of roof area to ceiling area.

When still air conditions prevail in the attic he radiation of heat through the air of the space is compensated by increasing the surface conductance of the roof and ceiling areas within the space from 1.65 (for still air) is 2.20 when computing Ur and Uc. If the air is in motion with a space a surface conductance larger than 2.20 is required.

The leakage of air into and out of a building may be the result of either of the action of wind, or of the differential in temperature between the inside and the outside air or of the chimney action of tall structures. Outward leakage may be the result of maintaining the air under pressure in the structure. In any event, the air leaking out of the space is replaced by an equal weight of air which comes from the outside. Infiltration occurs as the result of air passing through porous walls, through cracks in the walls, and through cracks about window and door openings. Infiltration with the corresponding exfiltration produces an additional load on either the heating or the cooling plant of a building. In heating, the incoming air must be warmed to the temperature maintained within the room; the outgoing air carries with it a quantity of heat equal to that necessary to heat the inleaking air, and this heat is lost from the structure. In summer cooling, air entering a room as a result of infiltration must be cooled to room temperature and its moisture content reduced when necessary.

On the basis of the estimated or measured quantities of air leakage the sensible heat losses due to infiltration may be expressed as:

$$H = (C_{pa})\ Qd\ (t_2 - t_1)$$

where:

H = the loss or gain of sensible heat, BTU per hour.
C_{pa} = means specific heat of air at constant pressure 0.24 for practical purposes.
d = density of the air as measured, lb. per cubic foot.
Q = air leakage in cubic foot per hour.
t_2 = higher air temperature.
t_1 = lower air temperature.

When the gain or loss of sensible heat is calculated for crack leakage, the linear feet or crack considered is multiplied by the above formula.

$$H = (C_{pa})\ Qd\ L\ (t_2 - t_1)$$

where:

L = linear feet of crack considered.

Since the amount of crack leakage is dependent upon wind velocity, width of the crack, the linear feet of the crack, etc., it is not possible to fix accurate values definitely for any or all of the foregoing items. Therefore, the calculation or the air infiltration by any method must be at best a reasonable approximation. The number of linear feet of window and door cracks to be used may be empirically fixed as: (1) rooms with one exposure, all of the linear feet of cracks in outside wall; (2) room with two exposures, the linear feet of crack in the outside wall having the greater amount of cracks; and (3) rooms with three or four exposures, the length of the cracks in the wall having the greatest amount, but in no case must less than one-half of the total cracks in the outside be used. The foregoing rule is based on the assumption that the angle of incidence of the wind on the exposed side or sides vary from 0 to 90 degrees.

Tables will give the number of air changes per hour exclusive of ventilation air supply, air infiltration through walls, and air infiltration through windows.

Procedure in making heat-loss calculations from given data is to either compute or fix the following items:

1. Separate net areas of the walls, glass, ceiling, or roof, and floors through which the transmission of heat will occur.

2. The over-all coefficients of heat transmission for the component parts of the building listed in item 1. These are to be taken from tables of data or calculated.

3. The inside air temperature, at the breathing level 5 feet above the floor, which is considered to be necessary when severe winter weather exists; also the air temperatures at the proper levels for the calculation of heat losses through the various exposed building areas.

4. The outside air temperature which is to be used for design purposes.

5. The computed losses of heat occurring at the various areas listed in item 1, based on the proper coefficients of heat transmission and the difference between the temperature of the inside and the outside air.

6. An estimate of the heat required to warm the inleaking cold air.

7. The total of the individual transmission losses are those due to air leakage. This final summation gives the estimated heat losses from the space considered, for the air temperature conditions chosen, after the room or building has been heated.

Fuel

Fuel may be anything which can be burned without great difficulty and which is available in sufficnent quantities at prices which are not prohibitive. The choice of fuel is a question of dependability, cleanliness, fuel availability, economy, operating requirements, and control. Principle fuels used for heating are: (1) coal of various kinds, sizes, and grades, and its derivative coke; (2) distillates of petroleum oils, known as fuel oils; and (3) either natural or manufactured gas.

The economic problem involved for finding the total cost of fuel for an estimated period hinges upon the amount of heat loss for that period. Most methods for estimating heat loss are investigating losses in similar buildings within the same locality or using an average of the amount of fuel consumed by similar types of buildings. Estimates based on computed heat losses without the benefit of operating data are wholly dependent on how well the computation represents the actual facts. Two methods which are based on computed data are the calculated heat loss method and the degree-day method.

The calculated heat loss method is theoretical and assumes constant temperatures for very definite hours each day throughout the entire heating season. It does not take into account factors which are difficult to evaluate such as opening windows, abnormal heating of the building, poor heating systems, winter heat gains, such as sun effect and many others. The heat losses are calculated as designated before. The general equation for calculation is:

$$F = \frac{H \quad (t - t_a)N}{E \quad (t_d - t_o)C}$$

where:

F = quantity of fuel or energy required.
H = calculated heat loss, BTU during design hour, based on t_o and t_d.
t = average inside temperature maintained during heating period, F. degrees.
t_a = average outside temperature through estimate period, F. degrees.

t_d = inside design temperature, F. degrees.
t_o = outside design temperature, F. degrees.
H = number of heating hours in estimate period.
E = efficiency of utilization of the fuel over the period, expressed as a decimal; not the efficiency at peak or rated load condition.
C = heating value of one unit of fuel or energy.

The degree-day method is based on consumption data which have been taken from buildings in operation, and the results computed on a degree-day basis. While this method may not be as theoretically correct as the calculated Heat Loss Method, it is considered by many to be of more value for practical use. Tables give the normal or average number of degree days which have occurred over a long period of years as were computed from daily mean temperatures recorded by the Weather Bureau. The number of degree-days for a calendar year was obtained by taking the difference between 65° F. and the mean temperature determined from a reading of the maximum and minimum thermometers for a particular locality. These daily values were then added to obtain a monthly, seasonal, or yearly normal. In general, attempts to apply the degree-day method to fuel consumption over a period of less than a month are of questionable value.

The general equation for calculating the probable fuel consumption by the degree-day method is:

$$F = U \times N \times D$$

where:

F = fuel consumption for the estimated period.
U = unit fuel consumption, or quantity of fuel used per degree-day per building load unit.
N = number of building load units (when available use calculated heat loss instead of actual amount of radiation installed).
D = number of degree-days for the estimate period.

Values of N depend on the particular building for which the estimate is being prepared and must be found by surveying plans, by observation, or by measurement of the building. Values of U are found in tables according to the fuel used.

It must be remembered that not all heat to supply heat losses comes from the fuel. As stated before, some of the heat may be the sensible heat given off by the occupant within the room. Other potential sources of heat are lights, motors, machinery, industrial processes, cooking, etc; however, people, gas, certain industrial processes, and cooking operations are also liberators of moisture which often must be given consideration of heating the additional air required for ventilation.

Heat allowances for potential sources are:

Source	Heat Allowance, BTU per Hour
1. Electric Lights (incandescent)	Total wattage x 3.412
2. Electric Motors	Kilowatt input x 3.412
3. Gas	500-1000 BTU per cubic foot of gas used.
4. Machinery driven from the outside.	Brake horsepower supplied to the machine x 2545

The solar radiation is to be considered because of the heat absorbed from the sun; however, the effect of solar radiation is very much less during the period of winter heating than during the period of summer cooling of buildings. For this reason solar radiation is not considered for winter heating.

Selection

The selection of a system means in general, the medium used for conveying the heat from the boiler to the heat disseminator. There are three mediums used: (1) steam, (2) hot water, and (3) air.

Some form of steam is suitable for any structure. The selection of the type of system is always influenced by: (1) local condition, (2) the first cost of installation, (3) the flexibility and control desired, (4) the maintenance necessary, and (5) the cost for either fuel or purchased steam.

Steam systems may be generally classified as one-pipe or two-pipe arrangements both of which can be operated with either gravity or mechanical return of the condensate to the boiler. One-pipe installations have only a single connection at the bottom of the heat disseminators. This means that the condensate must leave the radiator, convector, etc., through the same pipe which carried the steam into the emitting unit. Further designations of this type are: (1) air-vent, (2) relief, (3) air line, and (4) vapor. Two pipe systems have separate inlet and outlet connections to each unit, radiator, etc. The condensate leaves the unit through an outlet pipe placed at some distance from the steam inlet. The vacuum, steam system can be added to the designations of the one-pipe.

The hot water system is also subdivided into gravity and forced circulation. It is further subdivided into two general classifications which are either open or closed. Open systems have the expansion to tank freely vented to the atmosphere; closed systems do not have the expansion tank open to the air. Some systems have no expansion tank, and excessive water pressures are prevented by relief valves only.

The air systems are the warm air and hot-blast systems. The warm air system operates with register temperature of 175° F. or less. A desirable feature of a warm air system is that it circulates a larger quantity of moderately warmed air with more beneficial results than does the hot-air system handling a smaller quantity at high temperatures.

The actual selection of a system, in the end, depends somewhat on the past experience of the individual and the economical cost of installation and maintenance.

Design

Design involves the estimation of the heating load, the determination of the number and sizes of the heat disseminators required, the layout and sizing of piping, and the type and size of boiler or furnace to be used. For complete data, a good book on the subject and the Heating and Ventilating and Air Conditioning Guide is necessary.

Examples

The following pages are examples of heating requirements for various types of plants.

The first example is a single story building of brick construction with an asphalt shingle roof. It is of story and a half design to permit rise of an overhead crane in the shop section. The product manufactured is an oil field utility truck bed.

Heating Requirements

After considering first cost, maintenance, simplicity of installation, case of operation, flexibility, and operating expense, it was decided to use natural gas for all heating within the plant.

In the heat loss calculations that follow the data and formulas were taken from the Heating and Ventilating Reference Data Book. As a basis for computation an outside temperature of 5 degree F. was assumed as representing the lowest consistent temperature to be expected. The inside temperatures were selected as follows:

Shop	60°F.
Office, storeroom, and locker rooms	70°F.

For determining the transmission of heat through walls, floor, roof, and windows, the following formula was used:

$$H = A(D)U$$

where:

H = the total heat in BTU/hour passing through the section.

A = the area of the surface under consideration.
D = the temperature differential between the two sides of the area.
U = the coefficient of heat transmission of the particular material.

In determining the leakage infiltration around the doors and windows, the following formula was used:

$$F = .24(L)(P)(d)(D)$$

where:

F = the total infiltration in BTU/hour.
L = the leakage factor (taken from table I of the Heating and Ventilating Data Book.
P = the perimeter of the swinging section of the door or window.
D = the temperature differential between the two sides of the door or window.
d = the density of air (taken as .075).

The computation of these heat losses involved breaking the physical plant down into three separate areas: shop, upstairs office, and downstairs office, each of which had different heating needs.

Upstairs Office

1. Inside walls (wood with plaster board siding):
   A = 1590 sq. ft., D = 10°F., U = .33

   H = A(D)U = 1590(.33)(10) = 5250 BTU/hour

2. Inside windows (infiltration): d = .075, P = 474.6 feet
   L = 175, D = 10°F.

   F = .24(L)(D)(P)(d) = .24(474.6)(10)(175)(.075)
   = 14900 BTU/hour

3. Inside windows (ordinary soda glass):
   A = 660 sq. ft., D = 10°F., U = .433

   H = A(D)U = 10(660)(.433) = 2860 BTU/hour

4. Outside walls (12 in. brick):
   A = 520 sq. ft., D = 65°F., U = .32

   H = A(D)U = 65(.32)(520) = 10830 BTU/hour

5. Outside windows (ordinary soda glass):

$A = 330$ sq. ft., $D = 65^{\circ}F.$, $U = .433$

$H = A(D)U = 330(65)(.433) = $ 9000 BTU/hour

6. Outside windows (infiltration):
$d = .075$, $D = 65^{\circ}F.$, $L = 175$, $P = 152$

$F = .24(1)(P)(D)(d) = .24(175)(.075)(152)(65)$
$= $ 31100 BTU/hour

Downstairs Office and Locker Room

1. Outside walls (12 in. brick):
$A = 1500$ sq. ft., $D = 65^{\circ}F.$, $U = .32$

$H = A(D)U = 1500(.32)(65) = $ 31100 BTU/hour

2. Inside walls (wood with plasterboard siding):
$A = 1118$ sq. ft., $D = 10^{\circ}$ F., $U = .32$

$H = A(D)U = 1118(10)(.32) = $ 3700 BTU/hour

3. Inside walls (12 in. brick):
$A = 600$ sq. ft., $D = 10^{\circ}F.$, $U = .32$

$H = A(D)U = 600(.32)(10) = $ 1920 BTU/hour

4. Infiltration around doors:
$L = 110$, $P = 40$ ft., $D = 10^{\circ}F.$, $d = .075$

$F = .24\,(L)(P)(D)(d) = .24(110)(40)(.075)(10)$
$= $ 704 BTU/hour

Shop

1. Walls (12 in. brick);
$A = 18365$ sq ft., $D = 55^{\circ}F.$, $U = .32$

$H = A(D)U = 18365(55)(.32) = $ 323000 BTU/hour

2. Windows (ordinary soda goass):
$A = 3630$ sq. ft., $D = 55^{\circ}F.$, $U = .433$

$H = A(D)U = 3630(55)(.433) = $ 86500 BTU/hour

3. Floor losses (6 in. concrete):
$A = 675{,}000$ sq. ft., $D = 55^{\circ}F.$, $U = .32$

$H = A(D)U = 675{,}000(55)(.32) = $ 1,187,000 BTU/hour

4. Roof losses (asphalt shingle on wood sheath):
$A = 68700$ sq. ft., $D = 55^{\circ}F.$, $U = .59$

$H = A(D)U = 687000(55)(.59) = $ 2,230,000 BTU/hour

5. Window infiltration:
   L = 175, P = 1670 ft., D = 55°F., d = .075

   $F = .24(L)(P)(D)(d) = .24(175)(1670)(55)(.075)$
   $= 289,000$ BTU/hour

Total heat losses for the three plant areas are as follows:

Upstairs Office	73,940 BTU/hour
Downstairs Office	37,324 BTU/hour
Shop	4,114,700 BTU/hour

These heating needs are to be met with the following equipment:

Upstairs Office:

1 Reznor model 4630 unit heater with a capacity of 24,000 BTU/hour. Fuel consumption; 30,000 cu. ft. of natural gas per hour.
1 Reznor model 4660 unit heater with a capacity of 48,000 BTU/hour. Fuel consumption; 60,000 cu. ft. of natural gas per hour.

Downstairs Office:

1 Reznor model 4660 unit heater with a capacity of 48,000 BTU/hour. Fuel consumption; 60,000 cu. ft. of natural gas per hour.

Shop:

4 Dravo model 125 unit heaters, each of which has a capacity of 1,250,000 BTU/hour, and a fuel consumption of 6,240 cu. ft. of natural gas per hour.

The second example is a single story dairy building of concrete block construction located in Oklahoma City.

The data used in this determination were taken from Severns', Heating, Ventilating, and Air Conditioning.

Winter design temperature for Oklahoma City is 0 degrees F.

U = concrete blocks with inside plaster is .46.
U = single-pane windows is 1.13.
U = six-inch concrete floor is .90.
U = yellow pine, one-inch corkboard, tarred outside, plastered inside, is .17.
R = solar radiation for glass is 190.
I = solar radiation for walls is 210.
a = solar absorption for walls is .70.
e = radiation factor for walls is .11.

Processing Room

Inside temperature is 70 degrees F.

Heat Losses

Gross wall area	1520 sq. ft.
Window area	151 sq. ft.
Net wall area	1369 sq. ft.
Feet of crack (worst side)	78 feet
Floor area	1440 sq. ft.
Ceiling area	1440 sq. ft.

$H = UA(t-t_1)$

H (wall)	.48(1369)(70-0)	44,100 BTU. per hour
H (windows)	1.13(151)(70-0)	11,970 " " "
H (floor)	.90(1440)(70-50)	25,800 " " "
H (ceiling)	.17(1440)(70-0)	17,100 " " "
Infiltration, H	.24(075)(45)(70)(70-0)	3,680 " " "
Total Heat Losses		102,650 BTU. per hour

Heat Gains

Solar radiation:		
West wall area		380 sq. ft.
West window area		50 sq. ft.
H (walls)	380(210)(.7)(.11)	9,500 BTU. per hour
H (windows)	50(190)	6,140 " " "
Heat gain from men working	5(560)	2,800 " " "
Heat allowance for lights, motors, and machiners		15,000 " " "
Total Heat Gains		33,440 BTU. per hour
Net Heat Loss		102,650 BTU. per hour
		33,440 " " "
		69,210 BTU. per hour

Offices

Heat Losses

Inside temperature 75°F.

Outside wall area	680 sq. ft.
Inside wall area	260 sq. ft.
Window area	75.5 sq. ft.
Net outside wall area	604.5 sq. ft.
Floor area	618 sq. ft.
Ceiling area	618 sq. ft.
Length of crack (worst side)	37.6 ft.

H (outside wall)	604.5(.46)(75-0)	20,800 BTU. per hour
H (inside wall)	260(.35)(75-70)	455 " " "
H (windows)	1.13(75.5)(75-0)	6,350 " " "
H (floor)	.9(618)(75-50)	13,800 " " "
H (ceiling)	.17(618)(75-0)	7,870 " " "
Infiltration:		
H	.24(.075)(45)(37.6)(75-0)	1,900 " " "
Total Heat Loss		31,175 BTU. per hour

Heat Gains

Solar Radiation:		
West wall area	210 sq. ft.	
West window area	25 sq. ft.	
H (wall)	210(.7)(.11)(210)	4,750 BTU. per hour
H (windows)	190(25)	3,400 " " "
Heat gain from workers	5 (320)	1,600 " " "
Allowance for lights		4,000 " ' "
Total Heat Gain		13,750 BTU. per hour
		31,175 BTU. per hour
		13,750 " " "
Total Net Heat Loss		17,425 BTU. per hour

Shower and Locker Rooms

Heat Losses

Outside wall area	80 sq. ft.	Inside temperature 85° F.
Inside wall area	340 sq. ft.	
Window area	12.6 sq. ft.	
Floor area	104 sq. ft.	
Ceiling area	104 sq. ft.	
Length of crack (worst side)	12.6 ft.	
H (outside wall)	.46(80-12.6)(85-0)	2,750 BTU. per hour
H (inside wall)	.35(340)(85-70)	1,780 " " "
H (windows)	1.13(12.6)(85-0)	1,200 " " "
H (floor)	.9(104)(85-50)	3,220 " " "
H (ceiling)	.17(104)(85-0)	1,500 " " "
Infiltration:		
H	.24(.075)(45)(12.6) (85-0)	724 " " "
Total Heat Loss		11,174 BTU. per hour

Heat Gains

Solar Radiation:	
West wall area	80 sq. ft.
West window area	12.6 sq. ft.

H (walls)	80(210)(.7)(.11)	1,290 BTU. per hour
H (windows)	12.6(190)	2,400 " " "
Allowance for lights		1,000 " " "
Total Heat gain		4,690 BTU. per hour
		11,174 BTU. per hour
		4,690 " " "
Total Heat loss		6,484 BTU. per hour

Radiator Requirements

Peerless Cast Iron Column Radiators, Four Column, 26" high; emits 240 BTU. per hour per sq. ft. heating surface, when heating with steam. A Four Column, 26" radiator of this type has five sq. ft. of heating surface per section.

Processing Room

$\frac{33,400}{240}$ (Heat loss) 159 sq. ft.

$\frac{159}{5}$ 32 sections

Use four radiators of eight sections each.

Office

$\frac{17,425}{240}$ (Heat loss) 72.5 sq. ft.

$\frac{72.5}{5}$ 14.5 sections

Use one radiator of eight sections and two radiators of four sections.

Shower and Locker Room

$\frac{6,484}{240}$ (Heat loss) 26.1 sq. ft.

$\frac{26.1}{5}$ 5.2 sections

Use one radiator of six sections.

The third example is a warehouse of reinforced concrete with common brick facing.

Tabulation of Heat Losses for Building

The following tables illustrate the method employed in calculating and tabulating the heat loss for the building. The heating requirements are for a temperature of 72° F. for the office and toilet and 65° F. for the warehouse and basement, with 0° F. weather. Heat transmission for the outside walls per square foot for a temperature difference of 70° is .36. The heat lost through the first floor is based on a temperature difference of 72° - 30° or 42°F. The heat transmission per square foot per 1° difference in temperature per hour through the roof of stone concrete, 4 inches thick with 5-ply tar and felt, is .575; hence, for 42° it is: .575 x 42° or 24 BTU. per hour.

Room	Net Vol. Cu. Ft.	Net Wall a Sq. Ft.	Floor or Ceiling Sq. Ft.	Glass Area Sq. Ft.	Door Area Sq. Ft.
1	2	3	4	5	6
Office	6,000	422	500	90	28
Toilet	2,600	396	300	24	-
Milk & Grocery	22,400	1,290	1,600	270	120
Laundry	16,800	188	1,200	120	112
Basement	43,200	3,120	3,600	180	24
Totals	92,000	.....	7,200	...	...

Room	Transmission Loss BTU/Hour			Infiltration Loss BTU/Hour		
	Wall-Loss (.36) Col.3	Floor-or Ceiling Loss (24) Col.4	Glass Loss (78.8) x Col.5	Assumed No. air Changes/ Hour	Infil. Loss 1.26 x Col. 2 x Col. 10	Total Heat Loss, BTU. per hour
1	7	8	9	10	11	12
Office	15,200	12,000	7,100	2	15,100	49,400
Toilet	16,600	7,200	1,890	2	9,100	34,740
Milk-Grocery	50,000	38,200	21,300	6	170,000	279,300
Laundry	7,340	28,800	9,450	4	84,800	129,590
	Heat Losses = 20% of building losses					94,781
Total	......	......	......	...	......	587,811

Heat Losses for Building Under Average Conditions: (Average outside temperature 47°)

Room	Transmission Loss BTU/Hour			Infiltration Loss BTU/Hour		Total Heat Loss BTU/Hour
	Wall-Loss 10 x Col.2	Floor-or Ceiling Loss 5.75 x Col. 4	Glass Loss 25.5 x Col. 5	Assumed No. Air Changes/ Hour	Infil. Loss .36 x Col. 2 x Col. 10	
Office	4,220	2,880	2,000	2	4,330	13,430
Toilet	3,960	1,730	500	2	2,600	8,790
Milk-Grocery	12,900	9,200	6,100	6	48,400	76,500
Laundry	1,888	6,900	2,700	4	24,200	35,688
Basement	Heat Losses = 20% of building losses					26,900
Total	......	......	......	...	......	161,308

The heat lost through the first floor is based on a temperature difference of 72° - 62° or 10°. The heat transmission per square foot per 1° difference in temperature per hour through the roof of stone concrete, 4 inches thick with 5-ply tar and felt, is .575; hence for 10° it is: .575 x 10° or 5.75 BTU/hour.

Stove Capacities and Gas Consumption:

Room	Total Cap. BTU.	Ave. Fuel Used, BTU.	Cu. Ft. /Hour	Operation Time/Week	Cu. Ft. / Month
Office	50,000	13,430	14.9	48	3,080
Toilet	36,000	8,790	9.8	48	2,020
Milk-Grocery	280,000	76,500	85.0	60	22,000
Laundry	128,000	35,700	39.6	48	8,160
Basement	96,000	27,000	30.0	48	6,200
Totals	....	......	197.3	...	41,460

$$\frac{\text{Average Fuel used}}{\text{Heat Value of Fuel/cu. ft.}} = \text{cu. ft./hour}; \quad \frac{13,430}{900} = 14.9 \text{ cu. ft./hour.}$$

Natural Gas Charges

$.40 for first 50 MCF
.30 for next 100 MCF   or $.41 flat rate
.25 for excess

Gross rate - 10% above net

41 x 41,460 = $170/month or $2,040/year

CHAPTER XIV

ILLUMINATION

Illumination is a factor of primary importance in every industrial plant. The advantages of good light to industry are:[1]

1. Fewer accidents.
2. A more cheerful work place, resulting in improved morale among employees and decreased labor turnover.
3. Less eye strain.
4. Decreased spoilage and improved quality.
5. Neater and cleaner plant.
6. Better housekeeping by employees.
7. Increased production.
8. Lessens visual fatigue.
9. Lessens mental irritation.

It takes time to see--the eye is somewhat like a camera in this respect. An increase in illumination from one footcandle to a moderate level of approximately 20 footcandles (a condition often occuring upon the installation of the proper lighting system) results in increasing the speed of seeing approximately three times.[2] This improved perception affects practically everything the employee does. Some of the time saved by the reduced time required for seeing becomes available for production. No detail should be overlooked in plant construction to attain maximum employee efficiency with minimum expenditure of human effort. For example, the normally accepted best working height is 34 inches, but the best "seeing" height of 39 inches should be used where the

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[1] L. P. Alford, Cost and Production Handbook, p. 746.

[2] M. Luckiesh and F. M. Moss, The Science of Seeing, p. 157.

worker does more inspection than handling.[3] Exact numerical measurements of increased production under improved lighting conditions would be easy if the work remained unchanged, but the character of the work often changes and becomes more difficult.

A typical example was that experienced by the Public Buildings Administration of the Federal Works Agency and the Public Health Service of the United States Government at Washington, D.C., in a joint survey of a card-punch subsection of the Bureau of Internal Revenue. Between December 1945 and January 1946, lighting was corrected. During 1946 the character of the work changed, employees estimated that the work was more than 50 percent more difficult in 1946 than in 1945. Despite this large increase in difficulty of the job, there was an overall improvement of 5.5 percent in 1946 over 1945.[4]

Many investigations have found that good artificial lighting costs close to 1 percent of total pay roll. The increased production will pay for this many times over.[5]

High labor turnover is often a direct result of dim, gloomy, and poorly lighted working surroundings. The psychological effect connected with pleasant surroundings cannot be overemphasized.

The close correlation between the personal injury rates and illumination is not generally understood. In most cases where accidents are attributed to poor illumination, they occur because there is improper quality of illumination or practically no illumination at all. Many factors associated with poor

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[3] H. G. Fromm, "The Beautiful Plant is More Efficient," Factory Management and Maintenance, CV (November 1947), 76-79.

[4] "Test Proves Better Seeing Means More Production," Factory Management and Maintenance, CV (December 1947), 111-113.

[5] Alford, *op. cit.*, p. 743.

illumination, such as glare, light reflected from the work, and dark shadows, hamper seeing and cause after-images and excessive visual fatigue. Frequently, accidents which are attributed to the individual's carelessness can actually be traced to difficulty of seeing.[6]

Factors of Good Illumination

Providing good illumination involves many factors. The Illuminating Engineering Society recommends: quality, which includes the absence of glare, proper color, direction of light, and its diffusion; and quantity, or the amount of illumination required for safety, production, and maintenance.

Glare may be defined as a dazzling light. It is one of the most common and serious faults of lighting installations and causes discomfort, increases fatigue, reduced efficiency, and often increases accident hazard.

What general lighting for industry will be like in 10, 20, or 30 years is only a guess. In 1915, ten footcandles was considered ample light; by 1930 the recommendation for good light had doubled.[7] Recommended practice today specified 50 footcandles for general manufacturing areas. Hence, the future will bring further increases in the quantity of light, if it can be accomplished with comfort. To accomplish this, light should come from many directions. In addition to the high levels of illumination, there are other advantages to having light come from many directions. Harsh and dense shadows are largely eliminated, light penetrates deeper into the recesses of complicated parts. From such a source light is practically uniform in brightness and reflected glare is negligible. An installation at General Electric Company, Nelo Park, Cleveland,

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[6] Ibid., pp. 16-17.

[7] J. C. Forbes, "What's Ahead in Plant Lighting," Factory Management and Maintenance, CVII (February, 1949), 110-113.

has been made making use of a mixture of different colored lights to produce white light.[8] At the working level of a desk top or work bench, light of any desired color can be obtained simply by the mixture of light from various colored lamps. As the lamps are turned on and off, the shade of the combined light varies. If this principle were used in producing a ceiling of light, the effect would be a ceiling of varigated colors producing white light. Such a practice would add attractiveness to working conditions.

Colored light has an application where it is necessary to inspect color more carefully or to do color matching. Various colors in the work under inspection may be emphasized or diminished in strength under the color distortion of different light sources. Small units generating these different colors in equal energy levels are available.

Tables now available establish the glare rating for representative types of lighting equipment when used under various conditions of room dimensions and illumination levels. With these tables it is possible to predict, before actually installing the equipment, that the addition of a simple longitudinal louver between the lamps of an ordinary industrial two 40-watt fluorescent lamp unit will cut the glare factor of the lighting system in two.

To maintain good seeing conditions, artificial lighting is required where daylight does not prevail. The desirable daylight conditions are seldom sufficient for good seeing requirements. With natural lighting, the space along the windows is the best lighted area.

Windows should be washed frequently to provide greater efficiency. An accumulation of dirt over a six months' period will cause some windows to lose

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[8] Ibid., pp. 110-113

as much as 75 percent of their efficiency.[9]

Recommended levels of illumination

By research it has been found that, for best seeing, the brightness of areas surrounding the work-place should approach that of the work. This emphasizes the need of light-colored surroundings. The advisability of light surroundings along with the task difficulty were considered in establishing the following recommended values of illumination for industrial areas.[10] These values for the minimum footcandles, on task or 30 inches above floor, are:

1. Most difficult seeing tasks--finest precision work involving finest detail, poor contrasts and long periods of time; such as, extra-fine assembly, precision grading or extra-fine finishing--100 or more footcandles.

2. Very difficult seeing tasks--precision work--involving fine detail, fair contrasts and long periods of time; such as, fine assembly or high-seed work--100 footcandles.

3. Difficult and critical seeing tasks--prolonged work involving fine detail, moderate contrasts and long periods of time; such as, ordinary bench work and assembly machine shop work, finishing of medium-to-fine parts and office work--50 footcandles.

4. Ordinary seeing tasks--work involving moderately fine detail, normal contrasts and intermittent periods of time; such as, automatic machine operation, rough grading, garage work areas, switchboards, continuous processes and conference and file rooms--30 footcandles.

5. Casual seeing tasks--such as, stairways, reception rooms, active storage, washrooms and other service areas--10 footcandles.

6. Rough seeing tasks--such as, hallways, corridors, passageways and inactive storage--5 footcandles.

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[9] Alford, op. cit., p. 751.

[10] J. C. Forbes and E. A. Linsday, "Six Recommended Lighting Systems for Industry," Magazine of Light, XVII (No. 4 Issue, 1948), 20.

CHAPTER XV

MODERN INDUSTRIAL LIGHTING

General Lighting

High Bay Narrow Interior

Luminaries which concentrate the light in a relatively narrow beam are desirable for this application in order to efficiently provide the necessary illumination at the working plane. Equipment with wide distribution would direct much of its light to the side walls and window area where it would be very largely absorbed.

Incandescent or mercury sources are used for this application either alone or in combination, the type used being determined in part by the character of the work performed in the area, the footcandle level desired, and the facilities for mounting and servicing. Where color discrimination is not necessary, mercury lamps may be used with the advantage of long life and high efficiency. The use of the higher-wattage, such as, 3000-watt mercury lamp, in direct-lighting equipment should be considered only where the mounting height is 40 feet or more and the material being worked on is of a non-specular character. When color correction is necessary in the use of mercury equipment, at least 15 percent of the lumens should be produced by incandescent lamps in order to provide an appreciable color improvement. There is little economical advantage in a combination system where more than 60 percent of the lumens are produced by incandescent lamps.

High Bay Wide Interior

Equipment with a wide distribution may be used effectively in greater areas of this nature to provide a greater overlapping of light beams with a resultant reduction in shadow intensity and with higher vertical surface illumination.

In rows of luminaries near the building walls, concentrating equipment should be used to minimize the loss through wall and window absorption.

In addition to incandescent and mercury vapor lamps, which are recommended for narrow high bay interiors, fluorescent lamps are suitable for use in wide high bay areas where lower-brightness sources are desired. They are particularly necessary where specular materials such as airplane sections are being fabricated. Where proper facilities for servicing can be employed, such as cranes or extension platforms, mounting heights up to 50 feet are possible providing the width of the room is at least five times the mounting height. The use of the 100-watt fluorscent lamp in RLM luminaries may have an advantage from a maintenance standpoint due to the fact that fewer lamps and luminaries will be necessary to provide the required level of illumination.

Low Mounting

The lighting equipment selected to produce uniform illumination from low mounting heights is usually of the wide-angle distribution type. Luminaries which do not produce a wide distribution must be more closely spaced to avoid spotty lighting.

For low mounting-height incandescent installations, the RLM Standard Dome may be effectively used. Another type of equipment with lower brightness and better diffusion is the Glassteel Diffuser, which may be used with either filament or mercury vapor lamps. Fixtures designed for use with silvered bowl lamps provide another means of reducing the brightness of the light source.

The majority of industrial low mounting installations now being made use fluorescent lamps in RLM luminaries. Fluorescent RLM luminaries are available in the conventional open type, or with various forms of louvers, with glass covers, and in vapor-proof units. The wide distribution of this type of luminaire, its relatively low brightness, and its comparative coolness make it particularly suitable for the lower mounting heights. Maintained illumination levels of 50 footcandles are readily obtainable with fluorescent luminaries.

A popular practice in industrial lighting is to install fluorescent luminaires in continuous rows. If an original installation in continuous rows is not desired, it may be advisable to space the fixtures in such a way that an additional fixture can later be added between adjacent units to form a continuous line. In this way, illumination levels may be doubled without great additional wiring expense.

Localized General Lighting

Many industrial plants have machinery of such a nature or so located that it lends itself to the positioning of luminaries with specific reference to the working points. Where a uniform intensity of illumination is not necessary throughout the area, such a positioning of lighting equipment permits the obtaining of high levels at the particular work points and at the same time provides sufficient illumination for adjacent areas.

Supplementary Lighting

When the general level does not provide enough illumination for a particular task, supplementary lighting equipment should be employed. This produced the desired levels by concentrating light at the point of work. There are several methods of achieving this result depending on the size of the work area, its location, and the possible location of the lighting equipment.

Small Areas

Where areas are small and the lighting equipment can be mounted close to the task, adjustable brackets or fixed channels may be mounted on the machines or benches.

Individual incandescent lamps in small reflectors with adjustable arms supply up to 300 footcandles at distances of approximately ten inches.

Fluorescent lamps with individual reflectors mounted close to the working area will give more than 150 footcandles of high-quality, low-brightness illumination.

Larger Areas

Where the light must be projected on areas which cannot readily be reached by other methods or where reflectors mounted close to the work would interfere with the workman's operation, larger-wattage equipment mounted at a distance must be employed. Special reflectors are manufactured for this purpose. The PAR-38 and R-40 spot and flood lamps requiring no external reflector are particularly suitable for applications of this nature. The units should be located so that the operator does not cast a shadow on the work.

Low-Brightness Sources

Certain types of work such as typesetting and sheet metal work require a large, low-brightness source for best seeing conditions. Incandescent lamps in a large glass-covered fixture or in a large-area indirect lighting unit would be suitable.

Vertical Surfaces

When a high level of vertical illumination is needed on an operation such as an assembly line, fluorescent fixtures with a symmetric light distribution or symmetrical fixtures tilted to an angle can be mounted on each side of a conveyor. Elliptical angle reflectors with incandescent lamps can be used, but precautions must be taken to prevent glare if the operators are forced to look directly into them.

Inspection Lighting

In designing inspection lighting the following characteristics of the materials or objects to be examined should be considered: (1) composition, (2) finish, (3) form, (4) internal structure, (5) surface contour, and (6) color. The lighting must then be tailor-made to fit the seeing task imposed by these characteristics. Generally speaking, a large low-brightness source is best for most inspection work; however, surface irregularities are sometimes easier to detect when light strikes at a grazing angle.

The inspection of transparent materials such as bottles, glassware, and plastics can be accomplished by means of an illuminated inspectional panel facing the inspector and projecting light through the object.

Luminaire Mounting

Individual

Individual reflectors may be mounted directly on the ceiling, suspended by conduit or chain, or from messenger cable, to the desired mounting height.

Continuous

Continuous rows of fluorescent fixtures can be mounted in several ways. The various methods are illustrated below.

Fixtures for continuous-row mounting are little more expensive initially than individual fixtures and are considerably less expensive to install. The continuous trough acts as a wireway, and power need be supplied only at one convenient point along a row.

Although initial requirements may not warrant continuous rows of reflectors, it is good practice to install continuous wiring channels. Additional ballasts and reflectors can then easily be installed if the nature of the work should change so as to require additional illumination.

Arrangement

Orientation of luminaires with respect to the principal line of sight should be such as to provide the maximum shielding of the bare lamps. The light distribution curve of RLM-type fluorescent fixtures is practically the same in the planes parallel and perpendicular to the lamp axis. However, due to the shielding effect of the luminaire itself, the brightness is less annoying when the unit is viewed from the side.

Where luminaries must be mounted parallel to the normal line of sight, reflectors with closed ends should be used since they do afford some shielding. More comfortable conditions can be obtained by installing louvers which provide uniform shielding in all directions.

Where it is necessary to read cylindrical or conical dials on machines, best results can be obtained when fluorescent lamps are installed with the long axis perpendicular to the axis of rotation of the dial. Since dials are frequently placed in various planes around the machines, fluorescent luminaries may be installed in an arrangement so that their long axes run in two directions.

Types of Industrial Lighting Fixtures

General Lighting

To obtain general lighting from low mounting or localized illumination, the following types of industrial lighting fixtures are usable:

Description	Lamp Sizes
1. RLM reflector. Porcelain enameled steel. Available with either open or closed ends. (Glass-covered and louvered units available.)	Two 100-watt or two or three 40-watt fluorescent, also slimline lamps.
2. RLM Standard dome reflector. Porcelain enameled steel, Wide distribution with cut-off at 72 1/2 degrees from the vertical. (Dust-tight cover available with clear or stippled glass.)	75-watt to 1500-watt general service or white bowl lamps.
3. Glassteel Diffuser. Porcelain enameled reflector with opal glass enclosing globe used to obtain softer, better diffused light with a small upward component.	150-watt to 1000-watt general service lamp, 250-watt or 400-watt mercury vapor lamp.

Description	Lamp Sizes
4. Cast iron hood with threaded vapor-tight clear glass globe. Available with four types of porcelain enamel reflectors including the RLM dome.	75-watt to 300-watt general service.

For low mounting the type often used is:

Description	Lamp Sizes
1. RLM reflector for use with silvered bowl lamps. Some have aluminum inner reflector.	300 or 500-watt silvered bowl lamps.

In dusty or other hazardous places, where general lighting with low mounting is desired, the lighting fixture could be:

Description	Lamp Sizes
1. Porcelain enameled steel. Has dust and vapor-tight hinged cover. Meets Underwriters' requirements for certain hazardous conditions. (Explosion-proof units also available.)	Two or three fluorescent lamps.

Supplementary Lighting

A fixture for general uses when supplementary lighting is needed is:

Description	Lamp Sizes
1. Metal hood 3 feet wide by 10 feet long with indirect trough suspended below.	Four 200-watt incandescent lamps per 10 feet.

Where there has to be supplementary illumination and the mount is desired close to the working area the following types of industrial lighting fixtures are recommended:

Description	Lamp Sizes
1. Small deep bowl reflector of porcelain enameled steel. (Adjustable mounting arms available.)	15-watt to 100-watt general service.

Description	Lamp Sizes
2. Metal housing containing either a procelain enameled or aluminum reflector.	Tubular incandescent or fluorescent lamps.

For additional lighting for illumination of vertical surfaces, it is suggested to use:

Description	Lamp Sizes
1. Angle reflector. Porcelain enameled steel.	75-watt to 1000-watt general service.

When using spot or flood for supplementary lighting the following type is in general use:

Description	Lamp Sizes
1. PAR-38 or R-40 spot or flood. The projector and reflector lamps have self-contained reflectors. (Reflectors to be used with general service lamps are available with wide or narrow beams.)	150-watt or 300-watt.

CHAPTER XVI

ECONOMICS AND MAINTENANCE OF INDUSTRIAL LIGHTING SYSTEMS

When consideration is given to the lighting systems for a new plant or to replacing obsolete systems, one of the most pertinent questions asked is, "How much do they cost?" This is a timely question because there is quite a spread between the comparatively low cost of filament luminaires and the higher cost of mercury and fluorescent luminaires, all of which are suitable under some conditions for industrial operations. Amortization and operating costs should, of course, be considered in computing the "over-all cost" of a system; and in order to show how these items affect the economics of lighting, a detail cost analysis is given on pages 177 and 178 for three different designs of industrial lighting systems.

To explain the items in the development of these figures a short step-by-step analysis is given for a typical 40-watt fluorescent system. The luminaire under consideration consists of a channel eight feet long which houses the ballasts and wires and supports the sockets and reflectors for the four 40-watt open-and industrial type reflectors being used with two lamps in each.

If this 191-watt unit is used in a plant working on a one-shift, 8-hour basis, it is estimated that it would be turned on for about 2500 hours in a year's time so that the annual energy cost, assuming a one-cent rate, would be \$4.80; a two-shift basis requires about 4000 hours burning per year for which the energy cost would be \$7.60.

Item 15 in Figure 15-1 shows that the total annual cost of operating this particular luminaire is the sum of the costs for electrical energy, lamp replacements, and cleaning which amounts to \$9.60 under one-shift operation and \$12.40 under two-shift operation.

COST ANALYSIS OF INDUSTRIAL LIGHTING SYSTEMS

	FLUORESCENT		MERCURY		INCANDESCENT	
	Preheat-Start 40-watt, 8-ft. section, open-end industrial type unit 4 40-watt lamps, 118 volts 60 cycle.		Two 400-watt mercury lamps two-lamp ballast, 230 V., 60 cycle, twin porc. enamel wide spread reflectors		One 1000-watt incandescent lamp, procelain enameled reflector, 120 volts.	
1. Rated lamp lumens per luminaire	9200 (8400) (d)		32,000		21,500	
2. Watts per luminaire	191		870		1,000	
INITIAL COST PER LUMINAIRE INSTALLED (not including wiring system)						
3. Purchaser's net price (Less lamps) (a)	$30.00		$36.00		$ 6.50	
4. Installation cost (a) (b)	12.50		20.00		10.00	
5. Lamps--net (30 discount)	2.80		14.70		2.45	
6. Total	$45.30		$70.70		$18.95	
ANNUAL OPERATING COST PER LUMINAIRE	1-shift	2-shift	1-shift	2-shift	1-shift	2-shift
Energy at 1 per kw-hr.						
7. 1-shift 2500 hr. per yr.	$ 4.80		$21.70		$25.00	
8. 2-shift 4000 hr. per yr.		$ 7.60		$34.80		$40.00
9. Lamps: Hours Life	2500	4000	4000	6000	1000	1000
10. Number of lamps replaced per year	4	4	1.25	1.25	2.5	4.0
11. Annual cost of lamps	$ 2.80	$ 2.80	$ 9.20	$ 9.20	$ 6.15	$ 9.80
12. Labor for replacing lamps	.80	.80	.30	.30	.60	1.00
13. Total lamp cost	$ 3.60	$ 3.60	$ 9.50	$ 9.50	$ 6.75	$10.80
14. Cleaning luminaire-twice yr.	1.20	1.20	.80	.80	.30	.30
15. Total operating cost	$ 9.60	$12.40	$32.00	$45.10	$32.05	$51.10

Figure 15-1

COST ANALYSIS OF INDUSTRIAL LIGHTING SYSTEMS (contd.)

		FLUORESCENT		MERCURY		INCANDESCENT	
16.	Annual owning cost per luminaire (16 2/3 per cent of items 3 and 4	$ 7.10	$ 7.10	$ 9.30	$ 9.30	$ 2.80	$ 2.80
17.	Total annual cost per luminaire (Item plus 16)	$16.70	$19.50	$41.30	$54.40	$34.85	$53.90
	ANNUAL ILLUMINATION COST-- Assuming typical large area of which 80,000 sq. ft. is provided with 50 footcandles maintained in service.						
18.	Coefficient of utilization (A--50 percent to 30 percent)	.69	.69	.65	.65	.65	.65
19.	Maintenance factor (e)	.65	.60	.70	.65	.65	.65
20.	Number of luminaires (e)	100	108	28	31	46	46
21.	TOTAL COST FOR ASSUMED AREA	$1,670	$2,110	$1,160	$1,670	$1,600	$2,480
	PERCENTAGE	100	100	69	79	96	118

(a) Estimated.

(b) Includes cost of installing and wiring to branch circuits.

(c) Replacement cost per lamp for fluorescent conventional start is estimated to be double that for instant start, to include added expense of service of starters which are a part of the conventional-start system only. With instant-start and the smaller diameter lamps no starters are involved.

(d) Lumen values for all fluorescent systems based on white lamps (3500 degrees K.) for 4500 degrees white, lumen output is 5-10 percent lower.

(e) Maintenance factor includes loss of light to 70 percent rated lamp life, reduced by a further 20 percent for dirt collection.

(f) For other room conditions, number of luminaires is inversely proportional to coefficient of utilization.

Figure 15-1 (contd.)

It should now be emphasized that this total annual operating cost does not include any amortization charges for the investment required in purchasing and installing the equipment. A reasonable percent of this investment which in this case amounts to $32.50 should be charged off each year in order to get a true estimate of the annual owning and operating cost. A figure of 16 2/3 percent of the purchaser's net price for the fixture plus the installation cost is believed by the best authors to be a fair charge-off and therefore has been used in this analysis. It amounts to $7.10. When this is added to the cost of operation it gives a total annual cost per luminaire of $16.70 for one-shift operation or $19.50 under two-shift operation.

Continuing the analysis to develop the comparative annual owning and operating cost of several complete lighting systems, it is only necessary to establish the relative number of luminaires to be used in each of them in order to produce equal footcandles. It is therefore assumed that each lighting system is installed in an 8000 square foot section of a large industrial area, where the various types of equipment can be installed at the proper height to justify a Room Index of "A" and that the ceiling and walls have 50 percent and 30 percent reflection factors respectively. Under these conditions 100 of the 8-foot 40-watt units for one-shift operation will provide 50 footcandles in service and its estimated over-all annual cost of 100 x $16.70 or $1670. For the two-shift operation 108 units are found to be necessary because the average lumen output of fluorescent lamps having a life of 4000 hours is less than it is for lamps which fail at about 2500 hours of operation. In the case of the two-shift operation the estimated over-all cost is 108 x $19.50 or $2110. A study of these two over-all costs, due to operating conditions for each type of equipment, readily reveals that for the longer hours of burning per year there is a lower unit cost of light.

<u>Lamp Lumens Calculation</u>

General lighting design makes it possible to predertermine the lumens per square foot delivered to a horizontal work plane corresponding to the floor area. By this method the lighting engineer strives for practically diffused light and uniform intensity over an entire area. The lamps are evenly spaced without regard to furniture or machinery and are provided with reflectors to prevent glare, harsh shadows, and uneven illumination.

Although the eye adjusts itself to wide variations of intensity, the exact degree selected for a given case must depend upon the efficient, comfortable, practical, and economical fulfillment of the purposes of the illumination. When the lumens per square foot (footcandles) desired are known, the problem is to account for losses due to:

1. Room proportions.
2. Color of walls.
3. Color of ceiling.
4. Fixture efficiency.
5. Light distribution.

Thus, the total lamp lumens that must be generated by the lamps can be determined by use of the following formula:

$$\text{Lamp lumens required} = \frac{\text{footcandles x area of room}}{\text{coefficient of utilization x maintenance factor}}$$

To determine the lamp lumens per luminaire, divide the total lamp lumens required by the number of luminaires to be installed.

Cost of Lighting

A convenient method of calculating the daily cost of lighting follows:[1]

$$\text{Owning and Operating Cost per Day} = \text{Daily Owning Cost of Equipment} + \text{Daily Cost of Current Consumed} + \text{Daily Cost of Lamps Replaced}$$

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[1]C. J. Allen, "Light and Sales," Magazine of Light, XV (No. 5 Issue, 1946, 5.

$$\text{Daily Owning Cost of Equipment} = \text{Cost of Luminaires Installed (less lamps)} \times \text{Annual Owning Cost Rate}$$

$$\text{Daily Cost of Current} = \text{Total Kilowatts of Luminaires} \times \text{Daily Burning Hours} \times \text{Energy Rate (\$ per KWH)}$$

$$\text{Daily Cost of Lamps Replaced} = \frac{\text{Number of Lamps in Installation} \times \text{Daily Burning Hours} \times \text{Net Dollars per Lamp}}{\text{Lamp Life (Hours)}}$$

Lamp Replacement

All light sources, incandescent, fluorescent, and mercury, have average rated lives under specified operating conditions. Some lamps burn out before this average is reached, and other last longer than the average. It is to be expected, therefore, that there will be a variation in the number of burnouts during the life of an installation.

On new installations it is important to remember that there will be a wide variation in the replacement rate during the first year or two of service. In a specific installation of fluorescent lamps (1250 lamps burning 8 hours a day for 25 days a month with an average life of 5000 hours) the normal replacement rate, as calculated from the formula, is two lamps per day. The "normal rate" is the rate attained after sufficient replacements have been made so that burnouts occur entirely at random. While the lamps are new the replacement rate is well below normal, and as the original group of lamps approach the end of life the rate is at least 50 percent above normal. Thereafter, the rate varies in decreasing amounts above and below normal, until the installation has been in operation sufficiently long for the replacements to approach a constant rate.

The length of time required to achieve the normal replacement rate varies with the average rated life of the lamps. When fluorescent or mercury lamps are used, the number of hours the lamps are burned at each turn-on has a direct bearing on the life of the lamps. For example, a 40-watt fluorescent lamp burned for 3 hours each time it is turned on will have a life of approximately

2500 hours, whereas the same lamp burned for 12 hours per start will have a life of 6000 hours. For filament lamps the curve will be approximately the same, but the normal rate is reached sooner because of the shorter life of the lamps.

Cleaning Luminaire

Many modern factories have extremely high ceilings, and special devices are necessary to maintain the lighting equipment. Among these are: (1) step ladder, (2) extension ladder, (3) telescoping platform, (4) lowering-type hangers, (5) catwalk, and (6) traveling cranes.

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Typist: Mrs. John W. Wayne III

Draftsman: Joseph Downing