CHARTING AND DIAGRAMMING TECHNIQUES FOR OPERATIONS ANALYSIS

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OVERVIEW

- Objectives in using charts and diagrams to study work include the following:

1. **To permit work processes to be communicated and comprehended more readily**
2. **To divide a given work process into its constituent elements for analysis purposes**
3. **To provide a structure in the search for improvements**
4. **To represent a proposed new work process or method**

OVERVIEW

- **Charting categories:**

(1) network diagrams

(2) traditional industrial engineering charts and diagrams

(3) process maps.

OVERVIEW

- **To develop a description of the work process that is ultimately used to create the graphic:**
- *The analyst is intimately familiar with the process.*
- *The analyst observes and records information about the process.*
- *One-on-one interviews of those familiar with the process.*
- *Group interviews of those familiar with the process.*

OVERVIEW

- **Once the chart or diagram is created, it can be analyzed through:**

1. *Algorithmic.* The specific algorithm for the particular diagram is used. Examples include line balancing algorithms for assembly lines and critical path methods for project scheduling.
2. *Checklists.* In this case, the analyst reviews a series of general questions to assess whether they can be applied to the particular problem of interest.
3. *Brainstorming.* This is a group or team activity in which participants contribute recommendations about potential improvements in the process.
4. *Separating value-added and non-value-added operations.* This approach attempts to distinguish between those steps in the process that actually add value to the product or service from the customer's viewpoint and those that do not. ***Value- added steps*** are operations that (1) the customer considers important and (2) physically change the product or service. Potential non-value-added operations include rework, delays, unnecessary inspections, and unnecessary moves.

NETWORK DIAGRAMS

- A network diagram is used to model the precedence order in which work elements must be performed in assembly operations. Called a **precedence diagram**, nodes represent the assembly work elements, and arrows indicate the sequence in which the elements must be performed.
- Critical path method (CPM) and program evaluation and review technique (PERT) diagrams are network diagrams used to schedule the work activities in a project. The methods for analyzing the various network diagrams differ for the different applications, but the same basic format is used in constructing the diagrams.
- For network diagrams with two-way flows between nodes (e.g., materials moving in both directions between two departments), the maximum number of arrows is given by

$$\text{Maximum number of arrows possible} = n(n - 1)$$

- n = number of nodes in the diagram

NETWORK DIAGRAMS

- For network diagrams containing only one-way arrows (e.g., arrows indicating precedence order of work elements or activities), the maximum possible number of arrows between nodes in the network is given by the following:

$$\text{Maximum number of arrows possible} = \frac{n(n-1)}{2}$$

- Most network diagrams have fewer than the maximum values given by these equations.

TRADITIONAL INDUSTRIAL ENGINEERING CHARTING AND DIAGRAMMING TECHNIQUES

operation charts

process charts

flow diagrams

activity charts

Operation Charts

- ***Operation chart*** is a graphical and symbolic representation of the operations used to produce a product. There are two types of operations in an operation chart:

(1) processing and assembly operations

(2) inspection operations.

- Developing the detailed listing of operations for the components and their assembly into the final entity (e.g., product, subassembly) is only the first step in the operation chart analysis.
- The second step involves examination of the chart to discover possible improvements. Because the focus of the operation chart is on the materials of a product and the operations performed on them, the examination step consists of a questioning procedure aimed at the materials and operations. A systematic approach includes questions such as those offered in the checklist of Table 2.
- The third step in the use of the operation chart for an existing work situation is to develop proposals for improvement based on the results of the questioning procedure.

Operation Charts

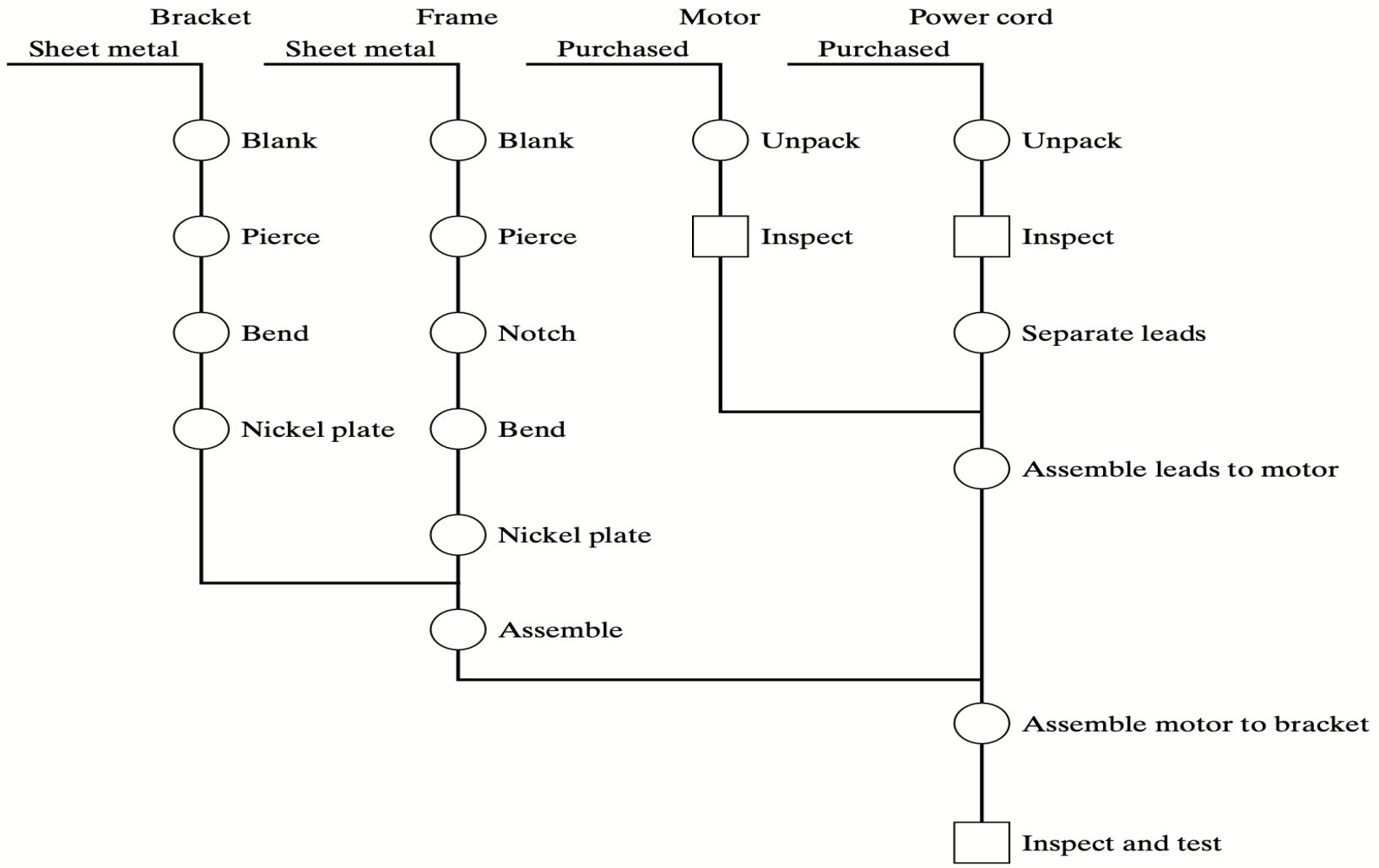


Figure 1 An operation chart for the subassembly of a product.

Operation Charts

TABLE 1 Symbols Used in Operation Charts

Symbol	Letter	Description
○	O	***Processing or assembly operation***. Processing operations consist of changing the shape, properties, or surface of a material or workpart. Assembly operations join two or more parts to form an assembly.
□	I	***Inspection operation.*** An inspector checks the material, workpart, or assembly for quality or quantity.

Operation Charts -

TABLE 2 Checklist of Questions Used to Analyze an Operation Chart

Questions related to material

What alternative starting material could be used (e.g., plastic rather than metal)?
Would a design change allow the part to be purchased as a standard commercially available item?
Could the functions of several separate components be combined into one component through a design change?
Make or buy decision: should this part be produced in our own factory or purchased from an outside vendor?

Question related to processing or assembly operations

What is the purpose of each processing operation?
Is the processing operation necessary?
Can operations be eliminated, combined, or simplified?
Is the operation time too high?
Could the processing operation be automated?
Could a different joining method be used for assembly (e.g., snap fit rather than threaded fasteners to save time)?

Questions related to inspection operations

What is the purpose of the inspection operation?
Is the inspection operation necessary?
Can the inspection operation be combined with the preceding processing or assembly operation?
If the operation is performed 100%, could it be performed on a sampling basis to reduce inspection time?
Could the inspection operation be automated?

Process Charts

- A ***process chart*** is a graphical and symbolic representation of the processing activities performed on something or by somebody.

- The chart consists of a vertical list of the steps performed on or by the work entity using various symbols to represent operations, inspections, moves, delays, and other activities. The principal types of process chart are: (1) the ***flow process chart***, used to analyze a material or workpiece being processed, (2) the ***worker process chart***, used to analyze a worker performing a process, and (3) the ***form process chart***, used to analyze the processing of paperwork forms.

Process Charts - Flow Process Chart

- The flow process chart uses five symbols, as defined in Table 3 to detail the work performed on a material or work part as it is being processed through a sequence of operations and other activities. Either iconic symbols or letter symbols can be used in constructing the chart, depending on the analyst's preference.

TABLE 3 Symbols Used in the Flow Process Chart

Symbol[a]	Letter	Description
○	O	***Operation***, usually a processing operation performed on the material at one location or workstation in which the physical shape or chemical characteristics of the material are changed. Assembly operations are unusual in a flow process chart.
□	I	***Inspection***, either to check for quality or quantity, performed at a single location or workstation.
→	M	***Move*** that involves transport of the material from one location to another, but not including moves within an operation at a workstation.
D	D	***Delay*** that occurs when the material does not or cannot proceed to the next activity—for example, a material waiting to be processed at a workstation, but other materials are ahead of it.
▽	S	***Storage*** in which the material is kept in a protected location to prevent unauthorized removal. Storage usually involves the use of a requisition to withdraw from storage, whereas a delay does not involve such a transaction.

[a]Based on symbols developed by the American Society of Mechanical Engineers (ASME). A simple arrow (→) has been substituted for the ASME move symbol (⇒) for ease of drawing.

Process Charts - Flow Process Chart

- The characteristic features of the flow process chart are shown in Figure 2. Alternative formats are possible, such as the standardized form shown in Figure 3.
- The operation and inspection symbols are sometimes combined if the processing step includes a processing operation combined with an inspection at the same workstation— for example, a worker buffing a part and periodically checking its luster. In this case, the symbol consists of a circle inside a square, with the diameter of the circle equal to the side of the square.
- This charting technique is used to study only a single material or work part rather than the multiple components of an assembly. For each symbol, a brief description of the work activity is listed in the flow process chart. In addition, the chart also indicates the distances for move activities and times for the other activities. The time values may be especially relevant for operations, inspections, delays, and storages.

Flow Process Chart					
Part No. 459011	Material: Steel C1045 forging		Description: Forgings processed in batches of 20		
Seq.	Activity Description	Symbol	Time	Distance	Analysis Notes
1	Forgings transported from forge shop	→		300 m	Forklift truck
2	Inspection of incoming forgings	□	1 hr		
3	Forgings moved and placed in storage	→		75 m	Hand truck
4	Storage	∇	7 days		Factory warehouse
5	Forgings retrieved from storage	→		75 m	Hand truck
6	Transport to machine shop	→		180 m	Forklift truck
7	Move to milling machine	→		20 m	Hand truck
8	Delay in queue for milling machine	D	5 hr		
9	Milling operation (roughing and finishing)	○	8 min/pc		Milling Machine No. 573
10	Move to drill press	→		20 m	Hand truck
11	Delay in queue for drill press	D	2 hr		
12	Drilling and tapping operations (6 holes)	○	3 min/pc		CNC Drill Press No. 226
13	Delay waiting for inspection	D	4 hr		
14	Inspection for machining operations	□	0.2 hr		
15	Delay waiting for transport to cleaning	D	3 hr		
16	Transport to finishing department	→		75 m	Forklift truck
17	Move to cleaning operation	→		10 m	Hand truck
18	Delay in queue for cleaning operation	D	30 min		
19	Cleaning operation (all parts in batch)	○	10 min		Solvent clean tank
20	Move to nickel plate operation	→		15 m	Hand truck
21	Delay in queue for nickel plate operation	D	45 min		
22	Nickel plate operation (all parts in batch)	○	20 min		Electroplating tank
23	Delay waiting for transport to storage	D	30 min		
24	Transport to storage	→		200 m	Forklift truck
25	Storage awaiting assembly	∇			Factory warehouse

Figure 2 A flow process chart used to detail the steps in the processing of a material. In the example shown, the material is a forging, and its processing consists of several machining operations, cleaning, and electroplating, but much of its time is spent in transport, delays, and storage.

Process Charts - Flow Process Chart

Date:	Flow Process Chart			Page ___ of ____
Analyst:	Approval:	Summary of Activities		
Job:	Part No:	Activity (symbols)	Count	Time	Distances
Material:		Operations (○, O)			
Description:		Inspections (□ , I)			
		Moves (→, M)			
		Delays (D, D)			
		Storages (∇, S)			

Seq.	Activity Description	Symbol	Time	Distance	Analysis Notes
1					
2					
3					
4					
5					
6					

Figure 3 A standardized form for the flow process chart that can be readily created using word processing software.

Process Charts - Worker Process Chart

- The ***worker process chart*** is used to analyze the activities of a human worker as he or she performs a task that requires movement around a facility. The symbols are virtually the same as those appearing in Table 3, but they are interpreted in terms of what the human worker does rather than what is done to a material.

- Table 5 summarizes the interpretations. The storage activity is difficult to interpret in the context of human work activity, so it is omitted. Analysis of the worker process chart in the search for improvements involves the same kinds of questions as in the flow process chart, only in the context of the worker performing the task of interest.

Process Charts - Worker Process Chart

TABLE 5 Symbols Used in the Worker Process Chart

Symbol	Letter	Description
○	O	***Operation*** performed by a worker at a single location or workstation. The operation may involve movements of materials within the workstation.
□	I	***Inspection***, either to check for quality or quantity, performed by a worker at a single location or workstation.
→	M	***Move*** in which the worker moves from one location to another as a regular element required in the task. It does not include moves within a workstation.
D	D	***Delay*** of the worker. Worker is forced by the situation to wait (e.g., waiting for an elevator). The waiting may involve moving, but the move is not a regular element required in the task (e.g., worker goes to the coffee machine while waiting for the elevator).

Process Charts - Form Process Chart

- The ***form process chart*** is used to analyze the flow of paperwork forms and office procedures that normally involve the processing of documents.

- Activities that occur in form processing require a change in the interpretation of the symbol. Additional symbols are also sometimes used to cover activities that are not associated with process charts for materials and workers.

- Symbols that can be used for the form process chart are presented and defined in Table 6.

Process Charts - Form Process Chart

TABLE 6 Symbols Used in the Form Process Chart

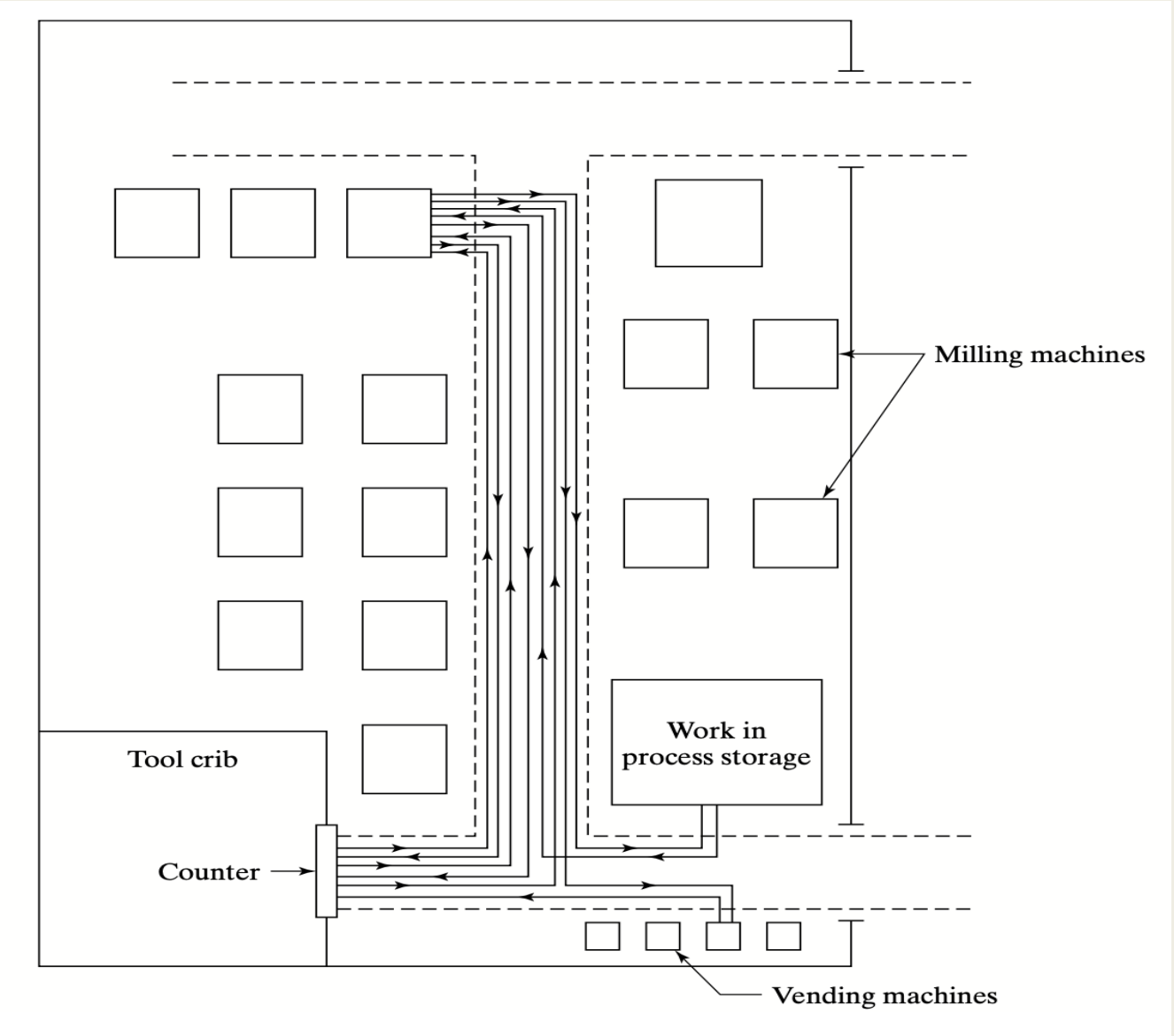
Symbol	Letter	Description
◎	C	***Creation*** of the form (circle in a circle). This symbol is used for the origination of the form, when the form is first initiated.
○	O	***Operation*** performed on the form at a single location or workstation. The operation may involve calculations, data entries, filling out forms, folding, photocopying, stapling, assembling multiple forms into one document, etc.
□	I	***Inspection*** to read information from the form or check for correctness performed at a single location or workstation.
→	M	***Movement*** of the form from one location to another by mail or human carrier.
D	D	***Delay*** of the form. Form is waiting to be worked on, located in an in-basket or similar location other than a storage file.
▽	S	***Storage*** in a file, normally in a file cabinet or other organized filing system. This usually involves storage for a considerable time period, rather than a temporary delay.
X	X	***Disposal*** of the form. The form or a copy is destroyed.

Flow Diagrams

- The ***flow diagram*** is a drawing of the facility layout but with the addition of lines representing movement of materials or workers to specific locations in the facility.
- The flow diagram is often used in conjunction with a process chart, especially when movement of the material, worker, or form is a major factor in the analysis.
- When used in connection with a process chart, the operations, inspections, delays, and storages at specific locations in the layout can be identified by numbers that are referenced to the activity numbers in the process chart.
- The flow diagram reveals problems in the workflow that may not readily be identified using the process chart alone. For example, if the workflow involves considerable backtracking, this can be seen in the flow diagram whereas it is indicated only as distances in the process chart. Other workflow problems may include excessive travel, possible traffic congestion, points where delays typically occur, and inefficient layout of workstations.

Flow Diagrams

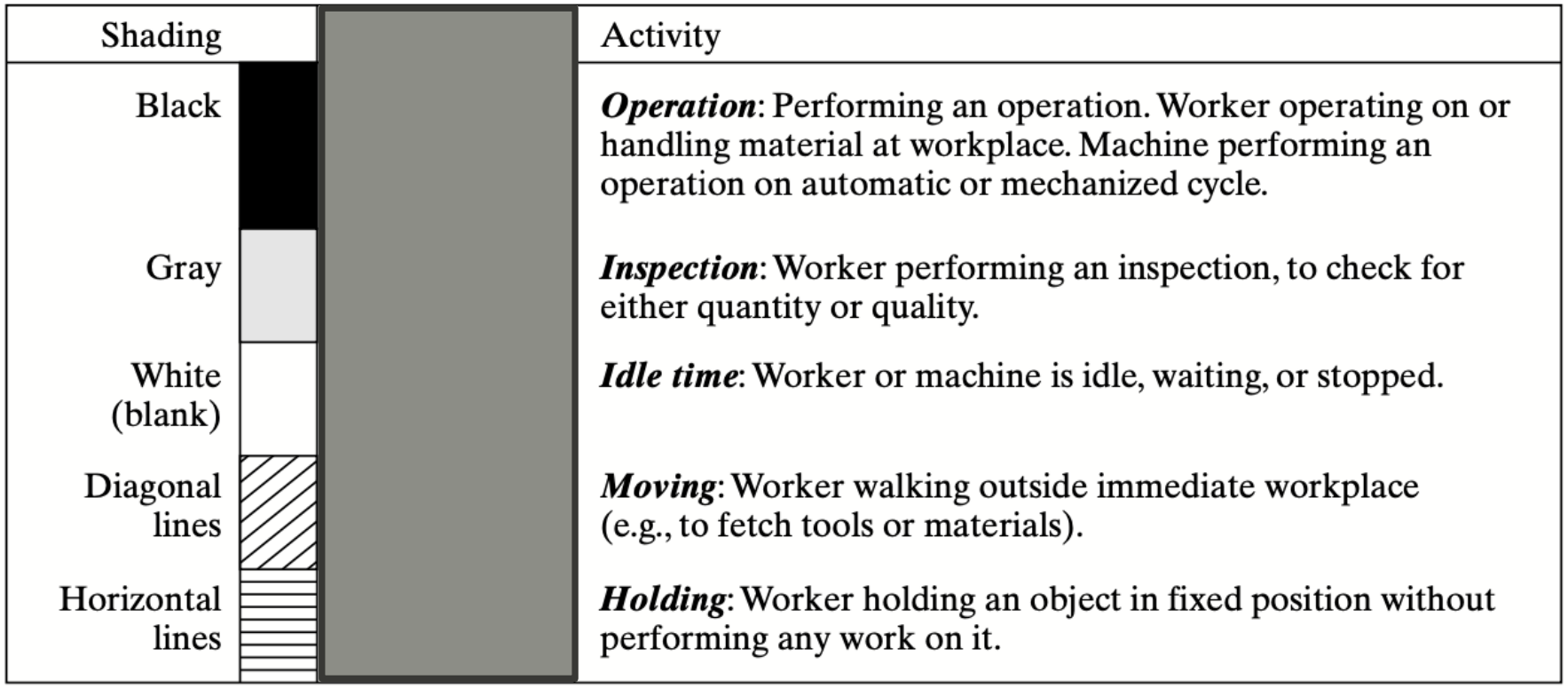
Flow diagram for a worker setting up a milling machine in the milling department.
Note the large number of trips back and forth between the milling machine and the tool crib, which suggests that the setup worker's task might be made more efficient if all of the items needed for the setup were collected in one trip.



Activity Charts

- An ***activity chart*** is a listing of the work activities of one or more subjects (e.g., workers, machines) plotted against a time scale to indicate graphically how much time is spent on each activity.
- The usual format is to provide brief descriptions of the activities against a vertical time scale, as shown in Figure 5 for a single worker performing a repetitive work cycle. Instead of using symbols for the work activities, as in the other charting and diagramming techniques described previously, the activities are indicated by vertical lines or bars. When bars are used, they are shaded or colored to indicate the kind of activity being performed.
- The usual format is to provide brief descriptions of the activities against a vertical time scale, as shown in Figure 5 for a single worker performing a repetitive work cycle.

Activity Chart



Shading	Activity
Black	***Operation***: Performing an operation. Worker operating on or handling material at workplace. Machine performing an operation on automatic or mechanized cycle.
Gray	***Inspection***: Worker performing an inspection, to check for either quantity or quality.
White (blank)	***Idle time***: Worker or machine is idle, waiting, or stopped.
Diagonal lines	***Moving***: Worker walking outside immediate workplace (e.g., to fetch tools or materials).
Horizontal lines	***Holding***: Worker holding an object in fixed position without performing any work on it.

Figure 6 Shading formats for activity charts.

Activity Charts

- Activity charts usually have more than one time scale. In Figure 5 two time scales are used, one for cumulative time during the work cycle and the second to indicate the time taken for each work activity.
- When activity charts are used to track several participants working together, the general name of the chart is a ***multiple-activity chart***, which consists of multiple columns, one for each participant. In this case, one time scale marks cumulative time during the cycle and a separate time scale indicates activity times for each of the columns.

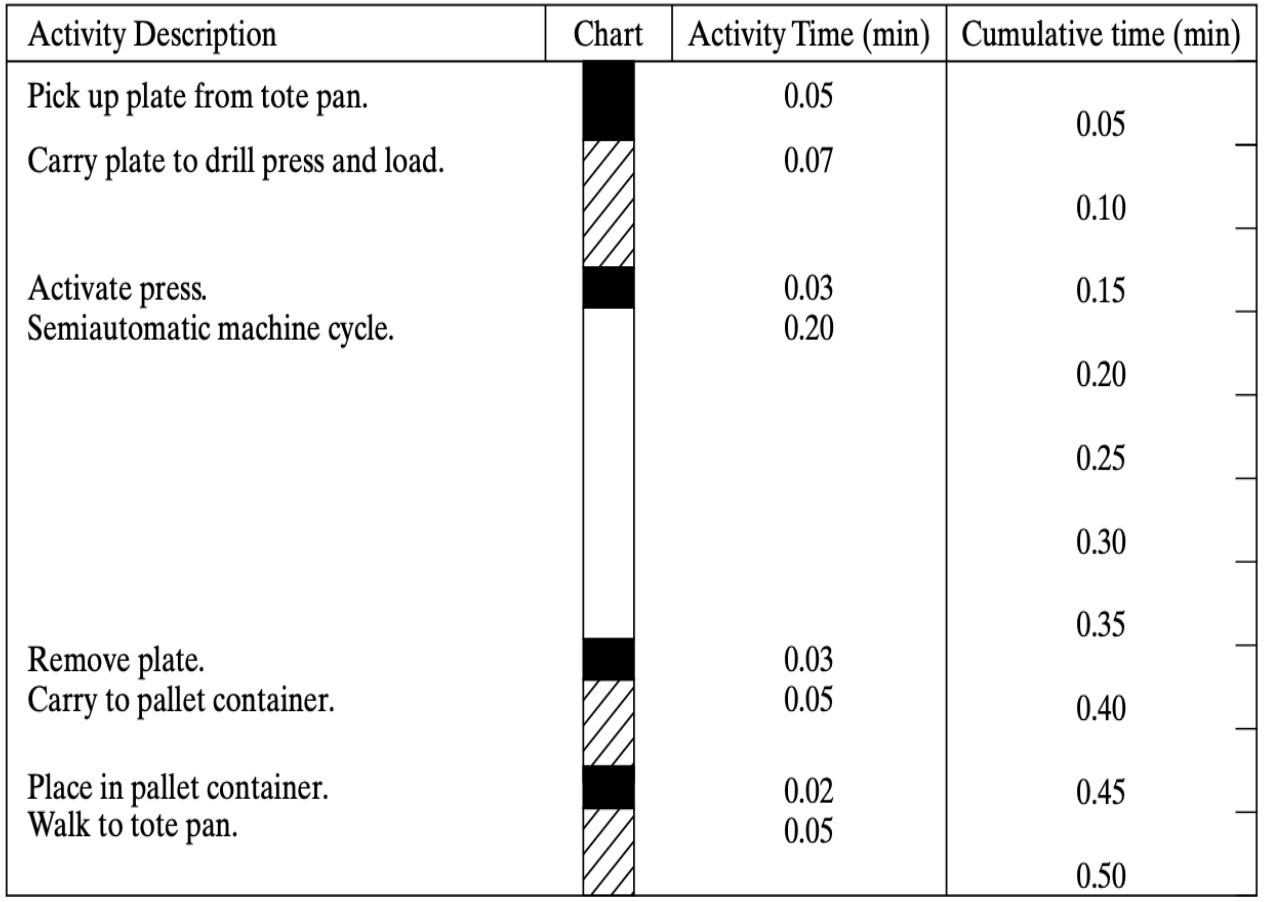


Figure 5 Activity chart for one worker performing a repetitive task.

Multiple Activity Chart

- ***Right-hand/left-hand activity chart***. This chart details the contributions of the right and left hands of one worker performing a task that is highly repetitive. The task is usually performed at a single workplace, and so the chart is sometimes referred to as a ***workplace activity chart***.
- Figure 7 illustrates a right-hand/left-hand activity chart for a task in which the worker is using his left hand as a work holder while his right hand performs nearly all of the activities. A methods analyst would seek to install a fixture to hold the work unit during the operation and to achieve a more even balance of the workload between the right and left hands.

Left Hand	Time (min)	Right Hand	Cumulative time (min)
Pick up board	0.08		0.08
Hold board	0.06	Pick up peg and insert	0.14
Hold board	0.06	Pick up peg and insert	0.20
Hold board	0.06	Pick up peg and insert	0.26
Hold board	0.06	Pick up peg and insert	0.32
Hold board	0.06	Pick up peg and insert	0.38
Hold board	0.06	Pick up peg and insert	0.44
Hold board	0.06	Pick up peg and insert	0.50
Hold board	0.06	Pick up peg and insert	0.56
Put assembly in tote pan	0.06		0.62

Figure 7 Right-hand/left-hand activity chart.

Multiple Activity Chart

- ***Worker-multimachine activity chart***. This chart is similar to the preceding except that the worker is responsible for more than one machine, and a work cycle must be developed that minimizes or eliminates ***machine interference*** (when one machine must wait for service because the worker is currently servicing another machine).
- Figure 8 illustrates the worker multimachine activity chart for two machines.

Worker		Time (min)	Machine 1		Time	Machine 2		Time	Cumulative time (min)
Walks to machine 1		0.2							
Services machine 1		0.3	Idle		0.3				0.5
Walks to machine 2		0.2	Automatic cycle						
Services machine 2		0.3				Idle		0.3	1.0
						Automatic cycle			
		0.5							1.5
Walks to machine 1		0.2			1.2				
Services machine 1		0.3	Idle		0.3				2.0
Walks to machine 2		0.2	Automatic cycle					1.2	
Services machine 2		0.3				Idle		0.3	2.5
Idle						Automatic cycle			
		0.5							3.0
Walks to machine 1		0.2			1.2				
Services machine 1		0.3	Idle		0.3				3.5
Walks to machine 2		0.2	Automatic cycle					1.2	
Services machine 2		0.3				Idle		0.3	4.0

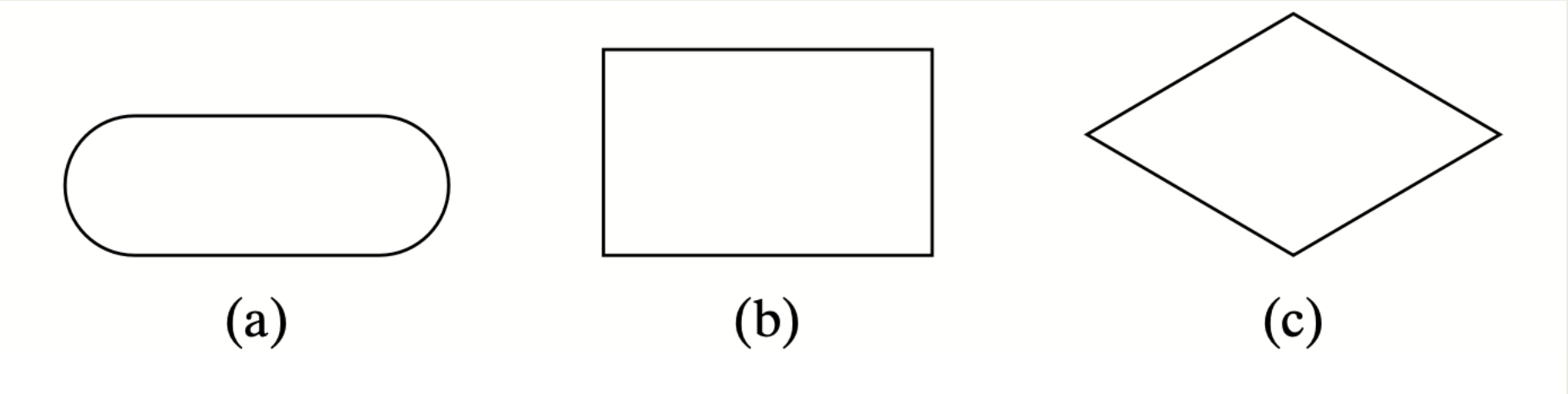
Figure 8 Worker-multimachine activity chart.

Process Maps

- As in other diagramming and charting techniques, process maps provide a detailed picture of the process or system of interest that is helpful for communicating and understanding by those involved in the operations analysis study.
- A ***process*** is defined as a sequence of tasks or activities that add value to one or more inputs to produce outputs. The inputs and outputs may be materials, products, information, services, or other form.
- The process must consist of more than one step, and the steps are linked together in a logical way. The process has a beginning point and an ending point, and its purpose in the organization is to provide something of value to its customers.

Process Maps

Symbols in the basic process map:(a) beginning/ending point of the process, (b) task or activity step, and (c) decision point.



Process Maps

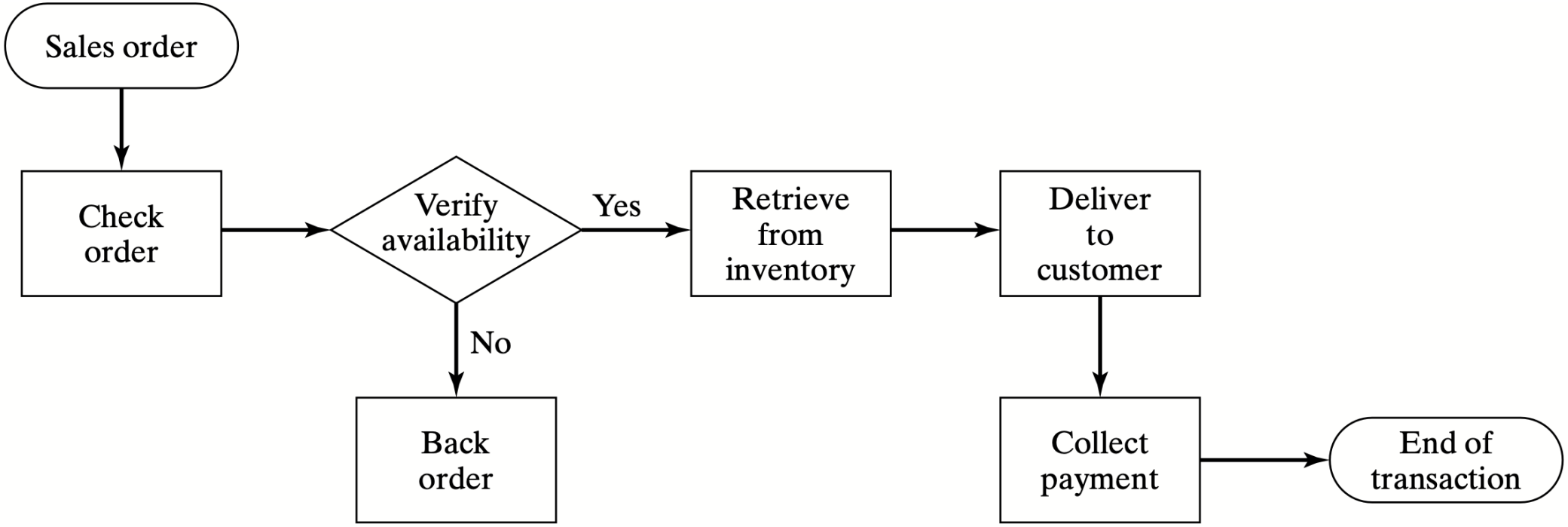


Figure 11 An example of a basic process map.

Process Maps

- A ***relationship map*** is a block diagram that shows the input-output connections among the departments or other functional components of an organization.
- The map consists of blocks that represent the departments and arrows to show the flow of work. A relationship map illustrates the pairs of supplier-customer relationships throughout the organization. Every department is a customer of another department, and it is also a supplier to some other department.
- Arrows indicate the flow of inputs that are processed and outputs that are produced in these supplier-customer relationships. The relationship map often includes the connections with external suppliers and/or customers of the organization, as well as the associated inputs and outputs.

Process Maps

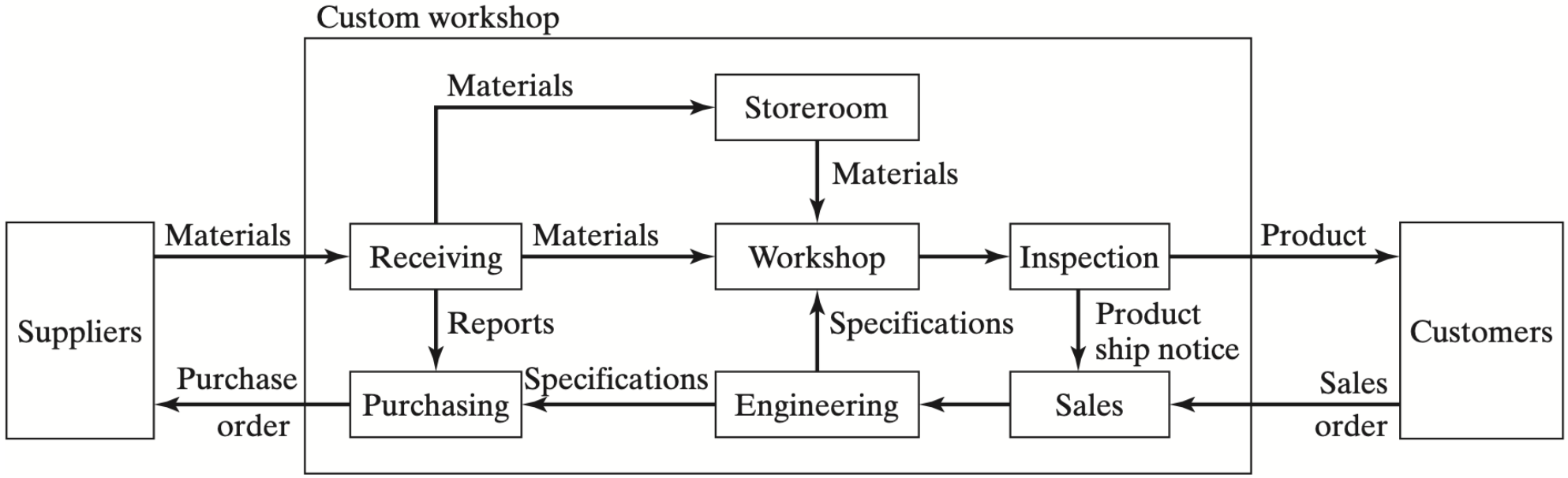


Figure 12 Relationship map for a custom workshop.

Process Maps

- A ***cross-functional process map*** is a block diagram that shows how the steps of a process are accomplished by the various departments or other functional groups that contribute to it. As shown in Figure 13, the departments are listed in rows separated by dashed lines.
- This format causes the cross-functional process map to also be known as the ***swim-lane chart***. Rectangular blocks represent activity steps in the process, and diamond-shaped blocks represent decision points. Arrows indicate the inputs and outputs for each block, as well as the sequence of steps.
- The cross-functional process map differs from the relationship map by showing the blocks as process steps (work activities), whereas the relationship map uses blocks to represent departments. The difference between the cross-functional process map and the basic process map is the use of rows (swim lanes) to show where the process steps are accomplished. In the basic process map, the process steps do not indicate in what department the work is done.

Process Maps

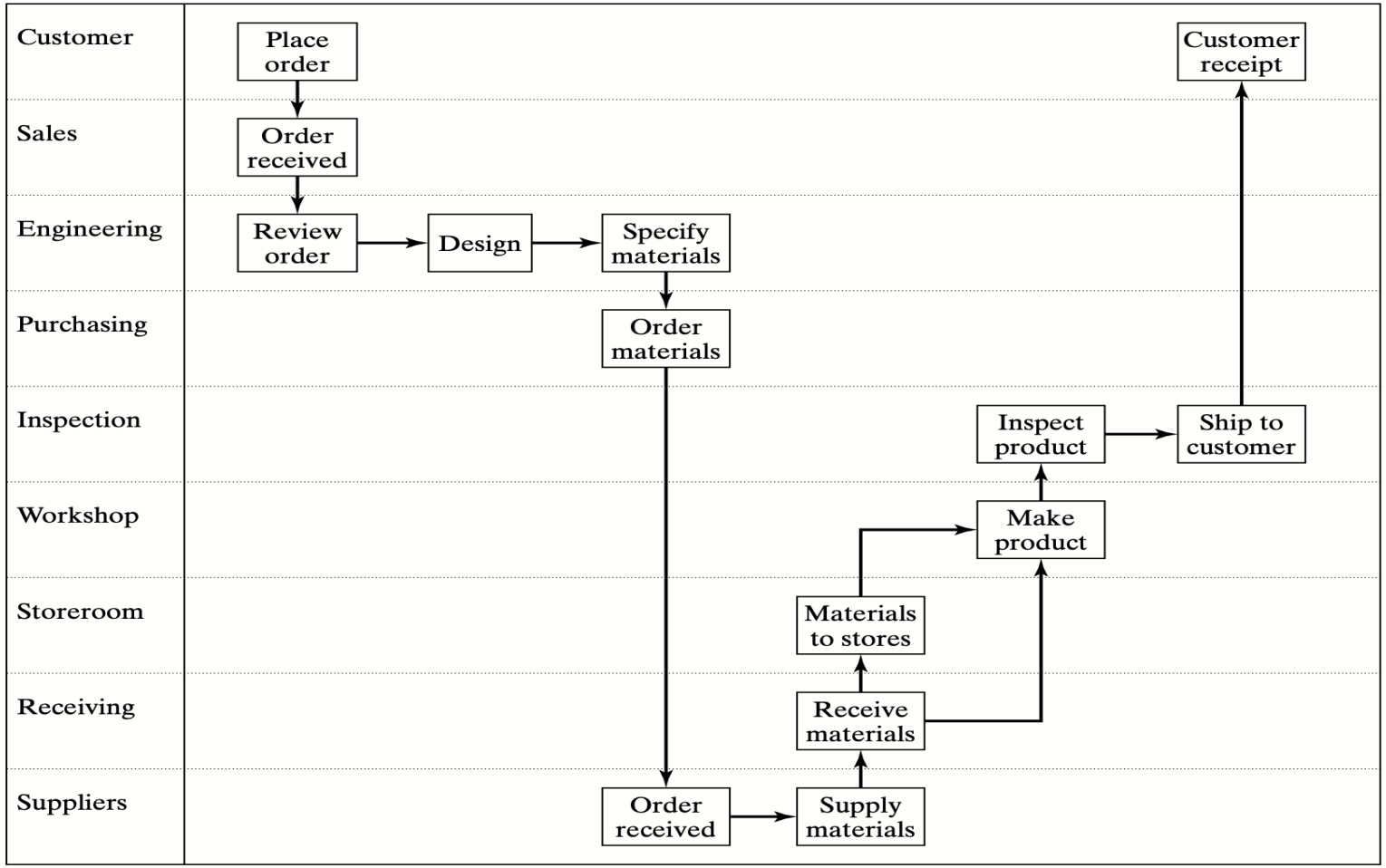


Figure 13 A cross-functional process map for a custom workshop.