Charting and Diagramming

Techniques for Operations Analysis

Chapter 9

Objectives of Charts and Diagrams

1. To permit work processes to be communicated and comprehended more readily
2. To use algorithms specifically designed for the particular diagramming technique
3. To divide a given work process into its constituent elements for analysis purposes
4. To provide a structure in the search for improvements
5. To represent a proposed new work process or method
How to Analyze the Chart or Diagram

- Algorithmic analysis
  - Line balancing (e.g., calculation of the minimum number of workstations and cycle time), critical path methods (e.g., calculation the longest path time in network diagram)

- Checklists
  - General questions applied to the particular process to assess whether they can be applied to the problem of interest

- Brainstorming
  - Team activity in which participants contribute recommendations

- Separating value-added and non-value-added operations
  - **value-added are operations that**: (1) the customer considers important
    (2) Physically change the product or service
  - **Non-value-added operations are such as**: rework, delays, unnecessary inspections and unnecessary moves.

Categories of Charts and Diagrams

1. **Network diagrams**

2. **Traditional industrial engineering charts and diagrams**
   - Operation charts
   - Process charts
   - Flow diagrams
   - Activity charts

3. **Block diagrams and process maps**
1. Network Diagrams (Precedence diagram)

- Consist of:
  - **Nodes** representing operations, work elements, activities or other entities
  - **Arrows** connecting the nodes indicate relationships among the nodes
    - Direction of work flow between nodes
    - Precedence among nodes

- Used to represent
  - Work elements in assembly line balancing
  - Sequences of processing operations
  - Work activities in Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT).

- Two-way flows (movement of materials):
  - Maximum number of arrows = \( n(n - 1) \)

- One-way arrows (precedence):
  - Maximum number of arrows = \( \frac{n(n - 1)}{2} \)
  - \( n \) is the number of nodes in the diagram

Example Network Diagrams

Applications

Sequential Operations in **Industry** OR **services**:

- **Manufacturing** (e.g., sequences of assembly process for the products between the workstations in a factory).

- **Medical services** (e.g., a surgery patient is first admitted and then move to a waiting room before arriving the operation room).

- **Transportation** (e.g., unloading the products from truck before transport them to the warehouse and then move the products to the shops)
Network Diagram Patterns

- **Pure sequential** – all work units follow the same exact sequence of operations and workstations
  - Work flow is identical for all work units

- **Mixed sequential** – different work units are processed through different operations
  - Different work flows for different types of work units

Work Flow Patterns

Network diagrams representing (a) pure sequential work flow and (b) mixed sequential work flow

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Network Diagram - Precedence Constraints

- Restrictions on the order in which work elements can be performed

Precedence diagram

- Arrow
- Node
- Time of the activity
- Number of units between the operations

Maximum number of arrows = \( n(n-1) \)

\[ = 12(12-1) = 132 \text{ arrows} \]

2. Traditional IE Charts and Diagrams

- Operation charts
- Process charts
- Flow diagrams
- Activity charts
Operation Charts

Graphical and symbolic representation of the operations used to produce a product

- Two types of operations:
  1. **Processing and assembly operations** (Symbol, \(\bigcirc\) OR Letter \(O\))
     - Changing the shape, properties or surface of a material or workpart
     - Joining two or more parts to form an assembly
  2. **Inspection operations** (Symbol, \(\square\) OR Letter \(I\))
     - Checking the material, workpart, or assembly for quality or quantity

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**Operation Chart for Subassembly of a Product**

- **Time of each task**
- **Component**
- **Subassembly**

The last column represents the base of assembly operation.
Checklist of Questions Used to Analyze an Operation Chart

- The focus of the operation chart is on the materials of a product and the operations on them.

- **Questions related to material**
  - What alternative starting material could be used?
  - Make or buy decision: should the part be produced in the factory or purchased?

- **Questions related to operations**
  - Is this processing operation necessary?
  - Can this operation be eliminated, combined, or simplified?
  - Could a different joining method be used?

- **Questions related to inspection**
  - Is this inspection necessary?
  - Could the inspection task be automated?

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Example: Operation Chart for a Pipe Clip manufacturing

Process Charts

- Graphical and symbolic representation of the processing activities performed on something or by somebody

- The chart using various symbols to represent operations, inspections, moves, delays and other activities.

Process Charts (Cont.)

- Principal types of process charts:

1. **Flow process chart** – analysis of a material or workpiece being processed

2. **Worker process chart** – analysis of a worker performing a task

3. **Form process chart** – analysis of the processing of paperwork forms
Flow Process Chart

Uses five symbols to detail the work performed on a material or workpart as it is processed through a sequence of operations and activities (see table 9.3, textbook page:238):

- **Operation** – processing of a material
- **Inspection** – check for quality or quantity
- **Move** – transport of material to new location
- **Delay** – material waiting to be processed or moved
- **Storage** – material kept in protected location

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Flow Process Chart

1- Flow Process Chart: The chart uses 5 symbols to analysis and detail the work performed on a material or work part through a sequence of operations and other activities.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Letter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>⊙</td>
<td>O</td>
<td>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.</td>
</tr>
<tr>
<td>□</td>
<td>I</td>
<td>Inspection, either to check for quality or quantity, performed at a single location or workstation.</td>
</tr>
<tr>
<td>→</td>
<td>M</td>
<td>Move that involves transport of the material from one location to another, but not including moves within an operation at a workstation.</td>
</tr>
<tr>
<td>⊖</td>
<td>D</td>
<td>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.</td>
</tr>
<tr>
<td>▼</td>
<td>S</td>
<td>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.</td>
</tr>
</tbody>
</table>

(see Textbook, Table 9.3, Page:238)
Flow Process Chart (Cont.)

- If the processing **operation** combined with an **inspection** at the same workstation: combine symbols - a circle inside a square

- The chart also indicates **distances** for move activities and **time** values for other activities

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**Example:** Type of flow process chart: Material flow process chart

**Type of task or name of operation:** Forging processed (metal manufacturing processing)
Flow Process Chart

2- Worker Process Chart: The chart is used to analyze the activities of a human worker as he or she performs a task that requires movement around a facility.

<table>
<thead>
<tr>
<th>TABLE 9.5 Symbols Used in the Worker Process Chart</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>☐</td>
</tr>
<tr>
<td>☒</td>
</tr>
<tr>
<td>→</td>
</tr>
<tr>
<td>D</td>
</tr>
</tbody>
</table>

(see Table 9.5, Page:242)

Flow Process Chart

3- Form Process Chart: The chart is used to analyze the flow of paper-work and office procedures that normally involve the processing of documents.

<table>
<thead>
<tr>
<th>TABLE 9.6 Symbols Used in the Form Process Chart</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>☐</td>
</tr>
<tr>
<td>☒</td>
</tr>
<tr>
<td>☒</td>
</tr>
<tr>
<td>→</td>
</tr>
<tr>
<td>D</td>
</tr>
<tr>
<td>▼</td>
</tr>
<tr>
<td>X</td>
</tr>
</tbody>
</table>

(see textbook, Table 9.6, Page:242)
Standard Form for Flow Process Chart

<table>
<thead>
<tr>
<th>Date:</th>
<th>Flow Process Chart</th>
<th>Page __ of ___</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst:</td>
<td>Approval:</td>
<td>Summary of Activities</td>
</tr>
<tr>
<td>Job:</td>
<td>Part No:</td>
<td>Activity (symbols)</td>
</tr>
<tr>
<td>Material:</td>
<td>Operations (O, O):</td>
<td></td>
</tr>
<tr>
<td>Description:</td>
<td>Inspections (C, I):</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moves (→, M):</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delays (D, D):</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Storage (V, S):</td>
</tr>
<tr>
<td>Seq.</td>
<td>Activity Description</td>
<td>Symbol</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Standard Form for Flow Process Chart
(Other form)
Checklist of Questions Used to Analyze a Flow Process Chart

- **Questions Related to Material**
  - Make or buy decisions: Should the part be produced in the factory or purchased from an outside vendor?

- **Questions Related to Operations and Inspections**
  - Is the operation time too high?
  - Is the inspection operation necessary?

- **Questions Related to Moves**
  - How can moves be shortened or eliminated by combining or eliminating operations?
  - Can the level of mechanization in material handling be increased?

- **Questions Related to Delays**
  - Is the delay avoidable?
  - What is the reason for the delay? Can the reason be eliminated?

- **Questions Related to Storage**
  - Is the storage necessary?
  - Why can’t the material be move immediately to the next operation?

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### Example of Flow Process Chart

(Material Process Chart)
Flow Diagram

Drawing of the facility layout with the addition of lines representing movement of materials or workers within the facility

- Arrows on the lines represent direction of movement
- Often used in conjunction with a process chart
- Can be used to detect excessive backtracking, which might be missed in a process chart

Example: Flow Diagram

Flow diagram for worker setting up a milling machine

Note the large number of trips back and forth between the milling machine and the tool crib
Example Material Process Chart:
Receiving and inspecting aircraft parts

1. Lifted from truck: placed on inclined plane
2. Slid on inclined plane
3. Slid to storage and stacked
4. Await unpacking
5. Case unstacked
6. Lid removed: delivery note taken out
7. Placed on hand truck
8. Trucked to reception bench
9. Await discharge from truck
10. Case placed on bench
11. Cartons taken from case: opened: checked replaced contents
12. Case loaded on hand truck
13. Delay awaiting transport
14. Trucked to inspection bench
15. Await inspection
16. Tee-pieces removed from case and cartons: inspected to drawing: replaced
17. Await transport laborer
18. Trucked to numbering bench
19. Await numbering
20. Tee-pieces withdrawn from case and cartons: numbered on bench and replaced
21. Await transport laborer
22. Transported to distribution point
23. Stored
1. Case lifted from truck: placed on inclined plane
2. Slid on inclined plane
3. Placed on hand truck
4. Trucked to unpacking space
5. Lid taken off case
6. Trucked to reception bench
7. Await unloading
8. Cartons taken from case: opened and tee-pieces placed on bench: counted and inspected to drawing
9. Numbered and replaced in case
10. Await transport laborers
11. Trucked to distribution point
12. Stored
Activity Charts

A listing of the 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

- Types of activity charts:
  - Right-hand/left-hand activity chart (a.k.a. workplace activity chart)
  - Worker-machine activity chart
  - Worker-multimachine activity chart
  - Gang activity chart (a.k.a. multiworker activity chart)

Activity Charts (cont.)

- The usual format of activity chart is to provide a brief descriptions of the activities against a vertical scale for a single worker performing a repetitive work cycle.

- In activity chart is used a vertical lines or bars instead of using symbols for the work activities.

- The lines or bars are shaded or colored to indicate the kind of activity.
Activity Chart

Activity chart for a worker performing a repetitive task

<table>
<thead>
<tr>
<th>Activity Description</th>
<th>Chart</th>
<th>Activity Time (min)</th>
<th>Cumulative (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pick up plate from tote pan</td>
<td></td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Carry plate to drill press and load</td>
<td></td>
<td>0.07</td>
<td>0.10</td>
</tr>
<tr>
<td>Activate press.</td>
<td></td>
<td>0.03</td>
<td>0.15</td>
</tr>
<tr>
<td>Semiautomatic machine cycle.</td>
<td></td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Remove plate.</td>
<td></td>
<td>0.03</td>
<td>0.35</td>
</tr>
<tr>
<td>Carry to pallet container.</td>
<td></td>
<td>0.05</td>
<td>0.40</td>
</tr>
<tr>
<td>Place in pallet container.</td>
<td></td>
<td>0.02</td>
<td>0.45</td>
</tr>
<tr>
<td>Walk to tote pan.</td>
<td></td>
<td>0.05</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Shading Formats for Activity Charts

<table>
<thead>
<tr>
<th>Shading</th>
<th>Color</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>Blue</td>
<td><strong>Operation:</strong> Performing an operation. Worker operating on or handling material at workplace. Machine performing an operation on automatic or mechanized cycle.</td>
</tr>
<tr>
<td>Gray</td>
<td>Yellow</td>
<td><strong>Inspection:</strong> Worker performing an inspection, to check for either quantity or quality.</td>
</tr>
<tr>
<td>White (blank)</td>
<td>White</td>
<td><strong>Idle time:</strong> Worker or machine is idle, waiting, or stopped.</td>
</tr>
<tr>
<td>Diagonal lines</td>
<td>Green</td>
<td><strong>Moving:</strong> Worker walking outside immediate workplace (e.g., to fetch tools or materials).</td>
</tr>
<tr>
<td>Horizontal lines</td>
<td>Red</td>
<td><strong>Holding:</strong> Worker holding an object in fixed position without performing any work on it.</td>
</tr>
</tbody>
</table>
Activity Charts (Cont.)

1- Right-hand/left-hand activity chart (workplace activity chart):

- This chart details the contribution of the right and left hands of one worker performing a task that is highly repetitive.

- The task usually performed at a single workplace so this chart is called also, *workplace activity chart*

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**Example: Right-Hand/Left-Hand Activity Chart**

Task involves placing pegs into a peg board

Note that left hand is used as a workholder

<table>
<thead>
<tr>
<th>Left Hand</th>
<th>Right Hand</th>
<th>Cumulative time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pick up board</td>
<td>Pick up peg and insert</td>
<td>0.08</td>
</tr>
<tr>
<td>Hold board</td>
<td>Pick up peg and insert</td>
<td>0.14</td>
</tr>
<tr>
<td>Hold board</td>
<td>Pick up peg and insert</td>
<td>0.20</td>
</tr>
<tr>
<td>Hold board</td>
<td>Pick up peg and insert</td>
<td>0.26</td>
</tr>
<tr>
<td>Hold board</td>
<td>Pick up peg and insert</td>
<td>0.32</td>
</tr>
<tr>
<td>Hold board</td>
<td>Pick up peg and insert</td>
<td>0.38</td>
</tr>
<tr>
<td>Hold board</td>
<td>Pick up peg and insert</td>
<td>0.44</td>
</tr>
<tr>
<td>Hold board</td>
<td>Pick up peg and insert</td>
<td>0.50</td>
</tr>
<tr>
<td>Hold board</td>
<td>Pick up peg and insert</td>
<td>0.56</td>
</tr>
<tr>
<td>Put assembly in tote pan</td>
<td>Pick up peg and insert</td>
<td>0.62</td>
</tr>
</tbody>
</table>
2- Worker-machine activity chart (Only one machine):

- This chart shows how the work elements and associated times are allocated between a worker and machine for the repetitive cycle of worker-machine system.

- The chart consists of two main columns, one for the worker and the other for the machine.

---

**Example: Worker-Machine Activity Chart**

- Finish small mill casting on a vertical miller machine
- Original method

<table>
<thead>
<tr>
<th>Worker Activity</th>
<th>Time (min)</th>
<th>Machine 1 Time (min)</th>
<th>Cum. Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walk to tote pan</td>
<td>0.13</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Pick up raw workpart and transport to machine</td>
<td>0.23</td>
<td>0.36</td>
<td>0.36</td>
</tr>
<tr>
<td>Load workpart and engage automatic cycle</td>
<td>0.12</td>
<td>0.48</td>
<td>0.48</td>
</tr>
<tr>
<td>Machine cycle</td>
<td>0.75</td>
<td>1.23</td>
<td></td>
</tr>
<tr>
<td>Unload finished part from machine</td>
<td>0.10</td>
<td>1.33</td>
<td>1.33</td>
</tr>
<tr>
<td>Transport part and deposit in tote pan</td>
<td>0.15</td>
<td>1.48</td>
<td>1.48</td>
</tr>
</tbody>
</table>
Example: Worker-Machine Activity Chart

- Finish small mill casting on a vertical miller
- Proposed method

<table>
<thead>
<tr>
<th>Worker Activity</th>
<th>Time</th>
<th>Machine 1</th>
<th>Cum. time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unload finished part from machine</td>
<td>0.10</td>
<td></td>
<td>0.10</td>
</tr>
<tr>
<td>Load raw part, engage auto cycle</td>
<td>0.12</td>
<td></td>
<td>0.22</td>
</tr>
<tr>
<td>Transport finished part, deposit in tote pan, walk to raw parts tote pan, pick up and transport to machine</td>
<td>0.51</td>
<td>Machine cycle</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Activity Charts (Cont.)

3- Worker-multimachine activity chart:

- This chart is similar to the Worker-machine activity chart expect that the worker is responsible for more than one machine.

- The work cycle must be developed that minimize or eliminates the *machine interference.*
Example: Worker-Multimachine Activity Chart

Can be used to indicate *machine interference* (when a machine must wait for service because worker is currently servicing another machine)

![Activity Chart](image)

Activity Charts (Cont.)

4- Gang activity chart (multiworker activity chart):

- This chart tracks the activities of two or more workers performing together as a team.

- The purpose of the activity chart analysis is to better coordinate the activities and balance the workload among the workers.
String Diagram

- Movement of workers and material

  **Examples in manufacturing:**
  - Material fed to/removed from continuous process, and is stored around the process.
  - An operative is looking after two or more machines.
  - Laborers are delivering materials to or removing work from a series of machines or workplaces.

  **Examples Outside manufacturing operations:**
  - In stores/shops where materials are being removed from or put away into racks or bins.
  - In restaurant/canteen kitchens during preparation of meals.
  - In control laboratories where routine tests are carried out.

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String Diagram (Cont.)

- The **string diagram** is a scale plan or model on which a thread is used to trace and measure the path of workers, material or equipment during a specified sequence of events.
- The **string diagram** is mostly used for studying workers’ movement.
- The work study person observes the movement of a worker over enough period of time. The observations may be recorded in a simple movement study sheet. Then, the string diagram can be constructed.
A simple movement study sheet

String Diagram (Cont.)

<table>
<thead>
<tr>
<th>Chart No.</th>
<th>Sheet No. 1 of 2</th>
<th>Operator(s):</th>
</tr>
</thead>
</table>

**Operation:** Transport biscuit tiles

- from inspection to storage
- bins and unload into bins

**Location:** Biscuit Warehouse

**Cross-reference:** String diagrams

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time dep.</td>
<td>Time arr.</td>
<td>Time elapsed</td>
<td>Move to</td>
<td>Notes</td>
</tr>
</tbody>
</table>

**Inspection bench (1):**
- to Bin 4
  - 13
  - 5
  - 32
  - 19

String Diagram (Cont.)
The examination of the diagram and the development of the new layout can now proceed with templates being used and the pins and templates being moved around until an arrangement is found by which the same operations can be performed with a minimum movement between them.

The string diagram is a useful aid in explaining proposed changes to management, supervisors and workers.

Example of a string diagram:

*Moving through several locations*

*(Original Method)*
Example of a string diagram:

Moving through several locations

(Improved Method)