Manual Assembly Lines

Sections:
1. Fundamentals of Manual Assembly Lines
2. Analysis of Single Model Assembly Lines
3. Line Balancing Algorithms
4. Other Considerations in Assembly Line Design
5. Alternative Assembly Systems
Manual Assembly Lines

- Work systems consisting of multiple workers organized to produce a single product or a limited range of products

- Assembly workers perform tasks at workstations located along the line-of-flow of the product
  - Usually a powered conveyor is used
  - Some of the workstations may be equipped with portable powered tools.

- Factors favoring the use of assembly lines:
  - High or medium demand for product
  - Products are similar or identical
  - Total work content can be divided into work elements
  - To automate assembly tasks is impossible
Why Assembly Lines are Productive

- **Specialization of labor**
  - When a large job is divided into small tasks and each task is assigned to one worker, the worker becomes highly proficient at performing the single task (Learning curve)

- **Interchangeable parts**
  - Each component is manufactured to sufficiently close tolerances that any part of a certain type can be selected at random for assembly with its mating component.
  - Thanks to interchangeable parts, assemblies do not need fitting of mating components
Some Definitions

- **Work flow**
  - Each work unit should move steadily along the line

- **Line pacing**
  - Workers must complete their tasks within a certain cycle time, which will be the pace of the whole line
Manual Assembly Line

- A production line that consists of a sequence of workstations where assembly tasks are performed by human workers.

- Products are assembled as they move along the line.
  - At each station a portion of the total work content is performed on each unit.

- Base parts are launched onto the beginning of the line at regular intervals (cycle time).
  - Workers add components to progressively build the product.
Configuration of an $n$-workstation manual assembly line

The production rate of an assembly line is determined by its slowest station.

- **Assembly workstation**: A designated location along the work flow path at which one or more work elements are performed by one or more workers
Two assembly operators working on an engine assembly line (photo courtesy of Ford Motor Company)
## Assembly Workstation

A designated location along the work flow path at which one or more work elements are performed by one or more workers.

**Typical operations performed at manual assembly stations**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Operation</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adhesive application</td>
<td>Electrical connections</td>
<td>Snap fitting</td>
</tr>
<tr>
<td>Sealant application</td>
<td>Component insertion</td>
<td>Soldering</td>
</tr>
<tr>
<td>Arc welding</td>
<td>Press fitting</td>
<td>Stitching/stapling</td>
</tr>
<tr>
<td>Spot welding</td>
<td>Riveting</td>
<td>Threaded fasteners</td>
</tr>
</tbody>
</table>
There may be more than one worker per station.

**Utility workers:** are not assigned to specific workstations.

They are responsible for

1. helping workers who fall behind,
2. relieving for workers for personal breaks,
3. maintenance and repair
Manning level

- Average manning level:

\[ M = \frac{w_u + \sum_{i=1}^{n} w_i}{n} \]

where

- \( M \) = average manning level of the line,
- \( w_u \) = number of utility workers assigned to the system,
- \( n \) = number of workstations,
- \( w_i \) = number of workers assigned specifically to station \( i \) for \( i = 1, \ldots, n \)
Manual methods
- Work units are moved between stations by the workers without powered conveyor

Problems:
- Starving of stations
  - The assembly operator has completed the assigned task on the current work unit, but the next unit has not yet arrived at the station
- Blocking of stations
  - The operator has completed the assigned task on the current work unit but cannot pass the unit to the downstream station because that worker is not yet ready to receive it.
To reduce starving,
  - use buffers

To prevent blocking,
  - provide space between upstream and downstream stations.

But both solutions can result in higher WIP,
  - which is economically undesirable.
**Work Transport Systems-Mechanized Methods**

- **Continuously moving conveyor**: operates at constant velocity
  - Work units are fixed to the conveyor
    - Worker moves alongside the line and back
  - Work units are removable from the conveyor

- **Synchronous transport (intermittent transport – stop-and-go line)**: all work units are moved simultaneously between stations.
  - Problem: Incomplete units; excessive stress. Not common for manual lines (variability).

- **Asynchronous transport**: a work unit leaves a given station when the assigned task is completed.
  - Variations in worker task times: small queues in front of each station.
Coping with Product Variety

- Single model assembly line (SMAL)
  - Every work unit is the same

- Batch model assembly line (BMAL) – multiple model line
  - Two or more different products
  - Products are so different that they must be made in batches with setup between

- Mixed model assembly line (MMAL)
  - Two or more different models
  - Differences are slight so models can be made simultaneously with no downtime
Coping with Product Variety

Advantages of mixed models over batch order models

- No production time is lost during changeovers
- High inventories due to batch ordering are avoided
- Production rates of different models can be adjusted as product demand changes.

Disadvantages of mixed models over batch order models

- Each station is equipped to perform variety of tasks (costly)
- Scheduling and logistic activities are more difficult in this type of lines.
Alternative Assembly Systems:

- **A single station manual assembly cell**
  It consists of a single workplace in which the assembly work is accomplished on the product or some major sub assembly of the product.

- **Assembly cells based on worker teams**
  It involves the use of multiple workers assigned to a common assembly task.

- **Automated assembly systems**
  Use automated methods at workstations rather than humans. These can be type IA or type IIIA manufacturing systems.
The assembly line must be designed to achieve a production rate sufficient to satisfy the demand. Demand rate $\bar{Y}$ production rate $\bar{Y}$ cycle time

Annual demand $D_a$ must be reduced to an hourly production rate $R_p$

$$R_p = \frac{D_a}{50S_wH_{sh}}$$

where

$S_w =$ number of shifts/week

$H_{sh} =$ number of hours/shift
Determining Cycle Time

**Line efficiency:** Uptime proportion. Accounts for lost production time due to equipment failures, power outages, material unavailability, quality problems, labor problems.

Production rate $R_p$ is converted to a cycle time $T_c$, accounting for line efficiency $E$

$$T_c = \frac{60E}{R_p}$$

where 60 converts hourly production rate to cycle time in minutes, and $E = \text{proportion uptime on the line}$
The cycle time $T_c$ establishes the ideal cycle rate for the line:

$$R_c = \frac{60}{T_c}$$

This $R_c > R_p$ because line efficiency $E$ is less than 100%, $R_c$ and $R_p$ are related to $E$ as follows:

$$E = \frac{R_p}{R_c}$$

Number of workers on the production line

$$w = \frac{WL}{AT}$$
Number of Workers Required

Work load: \[ WL = R_p \cdot T_{wc} \]

Available Time: \[ AT = 60E \]

The theoretical minimum number of workers (assuming workers spend all their time on the product) on the line is determined as:

\[ w^* = \text{Minimum Integer} \geq \frac{T_{wc}}{T_c} \]

where

\( T_{wc} = \text{work content time, min}; \quad T_c = \text{cycle time, min/worker} \)

If we assume one worker per station then this gives the minimum number of stations.
Theoretical Minimum Not Possible

- **Repositioning losses**: Some time will be lost at each station every cycle for repositioning the worker or the work unit; thus, the workers will not have the entire $T_c$ each cycle.

- **Line balancing problem**: It is not possible to divide the work content time evenly among workers, and some workers will have an amount of work that is less than $T_c$.

- **Task time variability**: Inherent and unavoidable variability in the time required by a worker to perform a given assembly task.

- **Quality problems**: Defective components and other quality problems cause delays and rework that add to the work load.
Repositioning losses occur on a production line because some time is required each cycle to reposition the worker, the work unit, or both.

- Repositioning time \( T_r \)

Service time = time available each cycle for the worker to work on the product

- Service time \( T_s = \text{Max}\{T_{si}\} \cup T_c \cap T_r \)

Repositioning efficiency \( E_r = \frac{T_s}{T_c} = \frac{T_c - T_r}{T_c} \)
Components of cycle time at several stations on a manual assembly line

\[ T_{si} = \text{service time}, \quad T_r = \text{repositioning time} \]
Line Balancing Problem

Given:

- The total work content consists of many distinct work elements
- The sequence in which the elements can be performed is restricted
- The line must operate at a specified cycle time

The Problem:

- To assign the individual work elements to workstations so that all workers have an equal amount of work to perform
The line balancing problem is concerned with assigning the individual work.

Two important concepts in line balancing are the separation of the total work content into minimum rotational work elements and the precedence constraints.

- **Minimum rotational work elements:**
  \[
  T_{wc} = \sum_{k=1}^{n_e} T_{ek}
  \]

  - \(T_{ek}\): Time to perform work element \(k\)
  - \(n_e\): Number of work elements
Work element times

- Work elements are assigned to station $i$ that add up to the service time for that station

\[ T_{si} = \sum_{k \in i} T_{ek} \]

- The station service times must add up to the total work content time

\[ T_{wc} = \sum_{k = 1}^{n} T_{si} \]
Precedence constraints: The variation in element times that make it difficult to obtain equal service times for all stations, there are restrictions on the order in which work elements can be performed. These technological requirements on the work sequence are called \textit{precedence constraints}.
Formulae:

- **Balance efficiency:**
  \[ E_b = \frac{T_{wc}}{wT_s} \]

- **Balance delay:**
  \[ d = \frac{(wT_s - T_{wc})}{wT_s} \]

- **Note that:**
  \[ E_b + d = 1 \]
Worker requirements:

Three factors that reduce the productivity of a manual assembly line:

- Line efficiency ($E$)
- Repositioning efficiency ($E_r$)
- Balancing efficiency ($E_b$)
- Labor efficiency on the assembly line = $EE_r E_b$
- More realistic value for the number of workers on assembly line is:

$$w^* = \text{Minimum Integer} \geq \frac{R_p T_{wc}}{60EE_r E_b} = \frac{T_{wc}}{E_r E_b T_c} = \frac{T_{wc}}{E_b T_s}$$
Work stations considerations:

- If the manning level is one for all stations, then the number of stations is equal to the number of workers.
  \[ n = \frac{w}{M} \]

- Total length of the assembly line:
  \[ L = \sum_{i=1}^{n} L_{si} \]

- Feed rate:
  \[ f_p = \frac{1}{T_c} \]

- Center to center spacing between base parts:
  \[ s_p = \frac{v_c}{f_p} = v_c T_c \]
- Tolerance time: 
  \[ T_t = \frac{L_{si}}{V_c} \]

- Ratio: 
  \[ \frac{T_t}{T_c} \approx 1.0 \]

- Elapsed time: 
  \[ ET = \frac{L}{V_c} = n \cdot T_t \]
To distribute the total work content on the assembly line as evenly as possible among the workers

- Minimize \( (wT_s - T_{wc}) \)

or

- Minimize \( \sum_{i=1}^{w} (T_s - T_{si}) \)

Subject to:

1. \( \sum_{k \in i} T_{ek} \leq T_s \)

2. all precedence requirements are obeyed
Line Balancing Algorithms

1. Largest candidate rule
2. Kilbridge and Wester method
3. Ranked positional weights method, also known as the Helgeson and Birne method

In the following descriptions, assume one worker per workstation
Largest Candidate Rule

List all work elements in descending order based on their $T_{ek}$ values; then,

1. Start at the top of the list and selecting the first element that satisfies precedence requirements and does not cause the total sum of $T_{ek}$ to exceed the allowable $T_s$ value

   When an element is assigned, start back at the top of the list and repeat selection process

2. When no more elements can be assigned to the current station, proceed to next station

3. Repeat steps 1 and 2 until all elements have been assigned to as many stations as needed
Solution for Largest Candidate Rule
Solution for Largest Candidate Rule

Physical layout of workstations and assignment of elements to stations using the largest candidate rule
Kilbridge and Wester Method

Arrange work elements into columns according to their positions in the precedence diagram

- Work elements are then organized into a list according to their columns, starting with the elements in the first column
- Proceed with same steps 1, 2, and 3 as in the largest candidate rule
Kilbridge & Wester Method

Arrangement of elements into columns for the K&W algorithm
A ranked position weight ($RPW$) is calculated for each work element

- $RPW$ for element $k$ is calculated by summing the $T_e$ values for all of the elements that follow element $k$ in the diagram plus $T_{ek}$ itself
- Work elements are then organized into a list according to their $RPW$ values, starting with the element that has the highest $RPW$ value
- Proceed with same steps 1, 2, and 3 as in the largest candidate rule
Other Considerations in Line Design

- Methods analysis
  - To analyze methods at bottleneck or other troublesome workstations
- Subdividing work elements
- Sharing work elements between two adjacent stations
- Utility workers
  - To relieve congestion at stations that are temporarily overloaded
- Changing work head speeds at mechanized stations
- Preassembly of components
  - Prepare certain subassemblies off-line to reduce work content time on the final assembly line
Other Considerations - continued

- Storage buffers between stations
  - To permit continued operation of certain sections of the line when other sections break down
  - To smooth production between stations with large task time variations
- Zoning and other constraints
- Parallel stations
  - To reduce time at bottleneck stations that have unusually long task times
Alternative Assembly Systems

- Single-station manual assembly cell
  - A single workstation in which all of the assembly work is accomplished on the product or on some major subassembly
  - Common for complex products produced in small quantities, sometimes one of a kind

- Assembly by worker teams
  - Multiple workers assigned to a common assembly task
  - Advantage: greater worker satisfaction
  - Disadvantage: slower than line production
Queries?
Thank You