Chapter 4: Estimating and Reducing Labor Costs

The objective of any process should be to create value (make profits), not to maximize the utilization of every resource involved in the process. We should not attempt to produce more than what is demanded from the market, or from the resource downstream in the process, just to increase the utilization measure.

Yet, underutilization provides opportunity to improve the process:

- If we can reduce the excess capacity at some process step, the overall process becomes more efficient (lower cost for the same output).
- If we can use capacity from the underutilized process steps to increase the capacity at the bottleneck step, the overall process capacity increases.

Objective: Discuss line balancing, which strives to avoid mismatches between what is supplied by one process step and what is demanded from the following process step.

4.1 Analyzing an Assembly Operation

It is March 2000 and Novacruz faced a demand of 125 / week.

[Figure 4.1: The Xootr by Novacruz]

[Figure 4.2: Lifecycle demand trajectory for Xooters]
A Labor Intense Process

Components → Activity 1 → Activity 2 → Activity 3 → Finished Xootrs

Activity Time:
- Activity 1: 13 min/unit
- Activity 2: 11 min/unit
- Activity 3: 8 min/unit

Bottleneck = resource with the lowest capacity.

\[
\text{Capacity} = \frac{\text{Number of resources}}{\text{Activity time}}
\]

\[
\text{Capacity} = \frac{1}{13 \text{ min/scooter}} = 0.0769 \text{ scooter/min}
\]

\[
= 4.6 \text{ scooter/hour}
\]

4.2 Time to Process a Quantity X Starting with an Empty Process

**Worker-paced system:** each worker is free to work at his or her own pace; if the first worker finishes before the first worker is ready to accept the parts, then the first worker puts the completed work in the inventory between them.

Time through an empty worker-paced process = Sum of the activity times

\[
= 13 + 11 + 8 = 32 \text{ minutes}
\]

**Machine-paced system:** all the steps must work at the same rate.

Time through an empty machine-paced process =

Number of resources in sequence \( X \) Activity time of the bottleneck step

\[
= 3 \times 13 = 36 \text{ minutes}
\]

\[
\text{Time to make } X \text{ units} = \text{Time through empty system} + \frac{X - 1 \text{ unit}}{\text{Flow rate}}
\]
**Exhibit 4.1**

**TIME TO PROCESS A QUANTITY X STARTING WITH AN EMPTY PROCESS**

1. Find the time it takes the flow unit to go through the empty system:
   - In worker-paced line, this is the sum of the activity times
   - In machine-paced line, this is the cycle time \( x \) the number of stations

2. Compute the capacity of the process (see previous methods). Since we are producing \( X \) units as fast as we can, we are capacity constrained; thus,
   \[
   \text{Flow rate} = \frac{X - 1}{\text{Process capacity}}
   \]

3. Time to finish \( X \) units
   \[
   \text{Time to make } X \text{ units} = \text{Time through empty system} + \frac{X - 1}{\text{Flow rate}}
   \]

---

**4.3 Labor Content and Idle Time**

**Labor content** = sum of activity times with labor = 13 min/unit + 11 + 8 = 32 min/unit

**Cost of direct labor** =

\[
\text{Total wages per unit of time} = \frac{\text{Flow rate per unit of time}}{\text{Wages per week}}
\]

\[
= \frac{\text{Scooters produced per unit of time}}{125 \text{ scooters / wk}}
\]

\[
= 3 \times \$12 / h \times 35 \text{ h/wk}
\]

\[
= \$10.08 / \text{scooter}
\]

**To correctly compute the cost of direct labor, we need to look at two measures:**

- The number of scooters produced per unit of time (the flow rate).
- The amount of wages we pay for the same time period.
**SUMMARY OF LABOR COST CALCULATIONS**

1. Compute the capacity of all resources; the resource with the lowest capacity is the bottleneck (see previous methods) and determines the process capacity.

2. Compute Flow rate = Min (Available input, Demand, Process Capacity);
   
   compute Cycle time = \( \frac{1}{\text{Flow rate}} \)

3. Compute the total wages (across all workers) that are paid per unit of time:
   
   Cost of direct labor = \( \frac{\text{Total wages}}{\text{Flow rate}} \)

4. Compute the idle time of each worker for each unit:
   
   Idle time for worker at resource i = Cycle time x (Number of workers at resource i) – Activity time at resource i

5. Compute the labor content of the flow unit: this is the sum of all activity times involving direct labor

6. Add up the idle times across all resources (total idle time); then compute

   \[
   \text{Average labor utilization} = \frac{\text{Labor content}}{\text{Labor content} + \text{Total idle time}}
   \]

---

**Table 4.1: Basic Calculations Related to Idle Time**

<table>
<thead>
<tr>
<th>Worker</th>
<th>Activity time</th>
<th>Capacity</th>
<th>Process capacity</th>
<th>Flow rate</th>
<th>Cycle time</th>
<th>Idle time</th>
<th>Utilization</th>
<th>Average Labor Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13 min/unit</td>
<td>1/13 unit/minutes = 4.61 units/hr</td>
<td>Minimum (4.61 units/h, 5.45 units/h, 7.5 units/h) = 4.61 units/h</td>
<td>Demand = 125 units/week = 3.57 units/hr</td>
<td>1/3.57 hours/unit = 16.8 minutes/unit</td>
<td>16.8 minutes/unit - 13 minutes/unit = 3.8 minutes/unit</td>
<td>3.57 / 4.61 = 77%</td>
<td>1/3 x (77.4% + 65.5% + 47.6%) = 63.5%</td>
</tr>
<tr>
<td>2</td>
<td>11 min/unit</td>
<td>1/11 units/minutes = 5.45 units/hr</td>
<td></td>
<td>Flow rate = Minimum (demand, process capacity) = 3.57 units/hr</td>
<td></td>
<td>16.8 minutes/unit - 11 minutes/unit = 5.8 minutes/unit</td>
<td>3.57 / 5.45 = 65.5%</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>8 min/unit</td>
<td>1/8 unit/minutes = 7.5 units/hr</td>
<td></td>
<td></td>
<td></td>
<td>16.8 minutes/unit - 8 minutes/unit = 8.8 minutes/unit</td>
<td>3.57 / 7.5 = 47.6%</td>
<td></td>
</tr>
</tbody>
</table>

Q 4.1
4.4 Increasing Capacity by Line Balancing

Comparing the utilization levels in Table 4.1 reveals a strong imbalance between workers. Imbalances within a process provide micro-level mis-match between what could be supplied by one step and what is demanded by the following steps. **Line balancing** is the act of reducing such imbalances. It provides the opportunity to:

- **Increase the efficiency** of the process by better utilizing the various resources
- **Increase the capacity** of the process by reallocating either workers from underutilized resources to the bottleneck or work from the bottleneck to the underutilized resources.

<table>
<thead>
<tr>
<th>Worker 1</th>
<th>Worker 2</th>
<th>Worker 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Utilization</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$3.57 / 4.61 = 77%$</td>
<td>$3.57 / 5.45 = 65.5%$</td>
<td>$3.57 / 7.5 = 47.6%$</td>
</tr>
</tbody>
</table>

Based on a **demand rate of 125 units per week** and the assumption that all three workers are a fixed cost for 35 hours per week, line balancing would change neither the flow rate (process is demand-constrained) nor the cost of direct labor (assuming the 35 hours per week are fixed).

Consider if **demand reaches 200 units per week**. Now the process is capacity constrained, specifically by worker 1 who can produce a scooter every 13 minutes while the market demand in one every 10.5 minutes. Worker 1 has a utilization of 100%, yet workers 2 & 3 have idle time:

- worker 2: utilization is $1/13 / 1/11 = 84.6\%$
- worker 3: utilization is $1/13 / 1/8 = 61.5\%$

**Cost of direct labor:**

\[
\begin{align*}
\text{Total wages per unit of time} &= \frac{\text{Wages per week}}{\text{Scooters produced per week}} \\
\text{Flow rate per unit of time} &= \frac{3 \times \$12 / h \times 35 h / wk}{161.5 \text{ scooters} / wk} \\
&= \frac{7.80 / \text{ scooter}}{}
\end{align*}
\]
Example Line Balancing

In an ideal scenario, we could just take the amount of work that goes into building a scooter, which is the direct labor content (32 minutes/unit), and split it up evenly between three workers = 32/3 = 10.66 minutes/unit = 640 seconds/unit

Moving tasks as shown in figure 4.5 the final activity times are:

Worker 1: 623 seconds per unit
Worker 2: 602 seconds per unit
Worker 3: 665 seconds per unit

Average labor utilization = Labor content / (Labor content + Total idle time) = 1,890 / (1,890 + 42 + 63 + 0) = 94.7%

New bottleneck is worker 3 resulting in a process capacity of 189.5 units / wk

Have reduced the cost of direct labor to $6.65 / unit.

Within the scope of this book we only consider cases where the sequence of tasks is given. Also, algorithms and heuristics exist that support line balancing in more complex settings, but that is not the focus for this text and course.
4.5 Scale Up to Higher Volume

- Increasing capacity by replicating the line
- Increasing capacity by selectively adding workers
- Increasing capacity by further specializing tasks

Figure 4.6: Three process lay-outs for high volume production

Figure 4.7: Line balance in a highly specialized line (different colors represent different tasks)
Figure 4.10: Trade-off between labor productivity and capital investment