Process Flow Analysis

& Tuffy Bike/XTM1

Operations Management

May 19, 2001
Purposes of process flow analysis

• Document the process
  – What gets done? Where? By whom?
  – In what sequence?

• Assess basic performance measures
  – Cost
  – Capacity
  – Inventory
  – Throughput time (delay)

• Identify bottlenecks and improvement opportunities
1) **Capacity (per time)** = maximum sustainable output per unit of time
   
   \[
   = \left( \frac{\text{# produced per cycle}}{\text{cycle time}} \right)
   \]

**Ex:** Calculating capacity of a batch process

- batch of 36 parts (lot size = 36)
- 6 hours to run a batch
- 1 hour of set-up/batch

<table>
<thead>
<tr>
<th>set-up</th>
<th>run</th>
<th>set-up</th>
<th>run</th>
<th>set-up</th>
<th>run</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 hr.</td>
<td>6 hrs.</td>
<td>1 hr.</td>
<td>6 hrs.</td>
<td>1 hr.</td>
<td>6 hrs.</td>
</tr>
</tbody>
</table>

Capacity = \[ \frac{\text{# parts/batch}}{\text{cycle time of batch}} \]

\[
= \frac{36 \text{ parts/batch}}{1 + 6 \text{ hrs./batch}} = 5.14 \text{ parts/hr.}
\]
2) **Utilization** = \( \frac{\text{Actual output per time}}{\text{Capacity per time}} \times 100\% \)

**Ex (cont):**
- batch process produces 35 parts/day
- 8 hrs./day production time

What is the utilization?

\[
\text{Utilization} = \frac{\text{actual # parts/time}}{\text{capacity}}
\]

\[
= \frac{35 \text{ parts/day}}{(5.14 \text{ parts/hr.}) \times (8 \text{ hrs/day})} \times 100\% = 85.1\%.
\]
3) *Bottleneck* = the resource that limits the capacity of the overall process

Why are bottlenecks important? (*The Goal*)
4) **Cycle stock** = the average inventory level resulting from batch production or ordering

\[ = \frac{1}{2} \times \text{(batch or lot size)} \]

**Ex:**
Produce a batch of 36 parts every 7 hours.
Demand = Production = \( \frac{36}{7} = 5.14 \) parts/hr.
What is the average cycle stock?

![Graph showing inventory over time](graph)

**Average inventory (cycle stock)** = \( \frac{1}{2} \times 36 = 18 \) parts

**NOTE:** Increasing the lot size increases cycle stocks for the same production rate.
5) **Little’s Law**

Relates avg. throughput time (delay), inventory and production rate

\[ N = \text{average inventory level} \]

\[ W = \text{average throughput time (avg. delay)} \]

\[ \lambda = \text{average production rate} \]

Little’s Law says ....

\[ N = \lambda W \]

That is, given any two of these measures of performance, the remaining one is uniquely determined.
Ex (cont.):
Produce a batch of 36 parts every 7 hours.
Demand = Production = 36/7 = 5.14 parts/hr.

Q: What is the delay (throughput time) at this stage of production?

A: From before, we know the average cycle stock is 18, so $N=18$.
The production rate is $\lambda = 5.14$ parts/hr.
So by Little’s Law, the average throughput time is $W = N/\lambda = 3.5$ hrs.

Ex:
Bread is produced at a rate of 7,000 loaves/hr.
Loaves take 20 min. to cool on the cooling rack.

Q: How many loaves must the cooling rack hold?

A: We know that the average time to cool is $W=20$ min. = 1/3 hrs.
The production rate is given as $\lambda = 7,000$ loaves/hr.
So by Little’s Law, the average number of loaves in the cooling rack is $N = \lambda W = 7,000/hr. \times 1/3 \text{ hrs.} = 2,333 \text{ loaves}$. The cooling rack must hold at least this many loaves.
Throughput vs. Cycle Time: Lincoln Tunnel Example

Case 1:

\( W = 20 \text{ min.} \)

throughput time = 20 min.

\( \lambda = 0.1 \text{ cars/min.} \)

cycle time = 10 min.

\( N = 2 \text{ cars} \)

Case 2:

\( W = 20 \text{ min.} \)

throughput time = 20 min.

\( \lambda = 1 \text{ car/min.} \)

cycle time = 1 min.

\( N = 20 \text{ cars} \)
Throughput time vs. cycle time

- **Cycle time**
  - The time between completion of units
  - The inverse of production rate (for unit production)
  - Answers the question:
    - How much time is there between each car that is exiting the tunnel?

- **Throughput time**
  - The time an individual units spends in the system.
  - Also called *waiting time*, *sojourn time*, *flow time*
  - Answers the question:
    If you painted an arriving car orange and put it in the tunnel, how much time would elapse before the orange car exited the tunnel?
Tuffy Bike: Basic steps

- Tube stock
- Cutting
- Welding
- Assembly
- Painting
- Ship
Tuffy Bike current process

order database

tube stock inv.
cutting
3 workers
30 min. cycle
6 frames/hr

cut frame WIP
250 units avg

welding
6 workers
45 min set-up
45 min welding
4 frames/hr
($30/hr)
painting
3 workers
30 min cycle
6 frames/hr
drying WIP
8 hrs drying time
30-40 units avg.
final assembly
7 workers
90 min cycle
4.67 frames/hr

phone orders from dealers

dealer

shipping
7 days
$25/unit

Demand: 600 units/mo. (160 hrs/mo. Production)

Assets: 1 month of receivables
$1M in plant & equipment

(Other data see note.)
# Tuffy Bike: Base Case

<table>
<thead>
<tr>
<th></th>
<th>set-up (min)</th>
<th>cycle (min)</th>
<th>total min./unit</th>
<th>$/hr.</th>
<th>$/unit</th>
<th>#workers</th>
<th>cap. (#/hr.)</th>
<th>utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>cut</td>
<td>0</td>
<td>30</td>
<td>30.0</td>
<td>$18.00</td>
<td>$9.00</td>
<td>3</td>
<td>6.00</td>
<td>63%</td>
</tr>
<tr>
<td>weld</td>
<td>45</td>
<td>45</td>
<td>90.0</td>
<td>$30.00</td>
<td>$45.00</td>
<td>6</td>
<td>4.00</td>
<td>94%</td>
</tr>
<tr>
<td>paint</td>
<td>0</td>
<td>30</td>
<td>30.0</td>
<td>$18.00</td>
<td>$9.00</td>
<td>3</td>
<td>6.00</td>
<td>63%</td>
</tr>
<tr>
<td>paint</td>
<td>0</td>
<td>90</td>
<td>90.0</td>
<td>$18.00</td>
<td>$27.00</td>
<td>7</td>
<td>4.67</td>
<td>80%</td>
</tr>
</tbody>
</table>

Income:

<table>
<thead>
<tr>
<th></th>
<th>$750.00</th>
<th>$(550.00)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rev/Unit</td>
<td>Gross Margin</td>
<td>$200.00</td>
</tr>
</tbody>
</table>

Cut Labor $ (9.00)
Weld Labor $(45.00)
Paint Labor $(9.00)
Assemble Labc $(27.00)
Shipping $(25.00)

Contrib. Marg. $ 85.00

Annual Revenu $ 5,400,000 100.0%
Mat.&Comp. $(3,960,000) -73.3%
Labor $(648,000) -12.0%
Shipping $(180,000) -3.3%

Net Contrib. $ 612,000 11.3%
Super. Labor $(150,000) -2.8%
Rent & Equip $(240,000) -4.4%

Oper. Profit $ 222,000 4.1%

Leadtime (working days):

- Welding WIP 8.3 (1)
- Processing 1.5 (2)
- Transport 7

Total 16.8

(1) Calculated in case: N=250 units in inventory divided by production rate of 30 units/day.

(2) 4 hrs of processing time + 8 hrs of drying time

Inventory #units cost/unit cost

- Orders 0 0 $
- Cut Frames 250 $ 559.00 $139,750.00 (1)
- Welded Frames 0 $ 604.00 $
- Painted Frames 0 $ 613.00 $
- Finished Goods 0 $ 640.00 $

Total $139,750.00

(1) 250 units given

Assets:

- Accts. Rec. $ 450,000 (1 month of sales)
- Inventory $ 139,750
- Plant & Equip $ 1,000,000

Total Assets $ 1,589,750

ROA 14%
Tuffy Bike: Batch production scenario

1) Product variety:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>lengths</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>heights</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>wheel diameters</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>color schemes</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>equipment packages (assembly options)</td>
</tr>
</tbody>
</table>

**200  Total Variants**

2) Assume all 200 variants are equally popular (unrealistic but simple)
3) Produce in batches (lots) of 30.

Batch production data:

<table>
<thead>
<tr>
<th></th>
<th>set-up (min.)</th>
<th>cycle time/worker (min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>cut</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>weld</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>paint</td>
<td>120</td>
<td>20</td>
</tr>
<tr>
<td>assembly</td>
<td>120</td>
<td>70</td>
</tr>
</tbody>
</table>
MTO Batch

Order queue
Form batches of 30 for each variant

Orders (600/mo.)

ship

cut → weld → paint → assemble

Cap. (#/hr)

Labor Cst. ($/unit)
Is this alternative any better?

Issues to consider:

- Unit cost
- Capacity/bottlenecks
- Throughput time (leadtime to customers)
- Product variety
- Level of investment (inventories)
- ROA