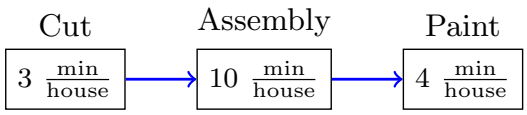
Your good friend Charlotte has invented a new birdhouse. It requires three steps to complete. The steps must be done sequentially, but she has a lot of equipment to do each task (5 saws, 6 electric screwdrivers, and 5 paintbrushes). Cutting out the shapes takes 3 minutes, assembly takes 10, and painting takes 4 minutes.



1. At first, Charlotte does all of the steps herself. That is, she cuts, assembles, and paints each unit.

   (a) What is the throughput time (in minutes) for a birdhouse if there is no inventory in the system (e.g. the first one through or a rush order)?

   A. 4 minutes
   B. 10 minutes
   C. 17 **minutes**
   D. 19 minutes
   E. 30 minutes

   $3\ minutes + 10\ minutes + 4\ minutes = 17\ minutes$

   (b) What is the constraining resource (or bottleneck of the operating system)?

   A. Cut
   B. Assembly
   C. Paint
   D. **Charlotte**

   Charlotte because Charlotte works for 17 minutes per house, making her the constraining resource.

   (c) What is the cycle time (in minutes per house) of the three-step process?

   A. 3 $\frac{\text{minutes}}{\text{house}}$
   B. 4 $\frac{\text{minutes}}{\text{house}}$
   C. 10 $\frac{\text{minutes}}{\text{house}}$
   D. 17 $\frac{\textbf{minutes}}{\textbf{house}}$
   E. 30 $\frac{\text{minutes}}{\text{house}}$

   The cycle time of the entire process is set by the bottleneck (Charlotte), which takes 17 $\frac{minutes}{house}$.

   (d) What is the capacity of the three-step process (in houses per hour)?

   A. 0.5 $\frac{\text{houses}}{\text{hour}}$
   B. 1 $\frac{\text{house}}{\text{hour}}$
   C. 3.53 $\frac{\textbf{houses}}{\textbf{hour}}$
   D. 6 $\frac{\text{houses}}{\text{hour}}$
   E. 20 $\frac{\text{houses}}{\text{hour}}$

   $60\ \frac{minutes}{hour} \times \frac{1\ house}{17\ minutes} = 3.53\ \frac{houses}{hour}$

   (e) What is worker utilization?

   A. 100%

B. 76%

C. $66.66\bar{6}\%$

D. 85%

E. $56.66\bar{6}\%$

Utilization is calculated as minutes of total direct labor content (DLC) / minutes available. Charlotte works $17 \frac{minutes}{house} \times 3.53 \frac{houses}{hour} = 60$ *minutes of total direct labor content (DLC). She is available for 60 minutes per hour, so:*

$$\begin{aligned} Utilization &= \frac{Direct\ Labor\ Content}{Time\ Available} \\ &= \frac{60\ minutes}{60\ minutes} \\ &= 100\% \end{aligned}$$

2. Charlotte hires two workers, trains them to each do one task, and now Charlotte does just one task so that each task is performed by one person. What are the performance measures now?

   (a) What is the throughput time (in minutes) for a birdhouse if there is no inventory in the system (e.g. the first one through or a rush order)?

   A. 4 minutes

   B. 10 minutes

   C. 17 **minutes**

   D. 19 minutes

   E. 30 minutes

   The time to make one has not changed, so the throughput time remains 17 minutes.

   (b) What is the constraining resource?

   A. Cut

   B. **Assembly**

   C. Paint

   D. Charlotte

   E. One of the workers besides Charlotte

   Because assembly now has the longest cycle time, the constraining resource is assembly.

   (c) What is the cycle time (in minutes per house) of the three-step process?

   A. 3 $\frac{\text{minutes}}{\text{house}}$

   B. 4 $\frac{\text{minutes}}{\text{house}}$

   C. 10 $\mathbf{\frac{minutes}{house}}$

   D. 17 $\frac{\text{minutes}}{\text{house}}$

   E. 30 $\frac{\text{minutes}}{\text{house}}$

   10 minutes per house, which is the cycle time of the assembly step (the constraining resource).

   (d) What is the capacity of the three-step process (in houses per hour)?

   A. 0.5 $\frac{\text{houses}}{\text{hour}}$

B. 1 $\frac{\text{house}}{\text{hour}}$

C. 3.53 $\frac{\text{houses}}{\text{hour}}$

D. 6 $\frac{\textbf{houses}}{\textbf{hour}}$

E. 20 $\frac{\text{houses}}{\text{hour}}$

$60\ \frac{minutes}{hour} \times \frac{1\ house}{10\ minutes} = 6\ \frac{houses}{hour}$

(e) What is worker utilization?

A. 100%

B. 76%

C. $66.66\bar{6}\%$

D. 85%

E. $56.66\bar{6}\%$

Altogether, the workers work $17\ \frac{minutes}{house} \times 6\ \frac{houses}{hour} = 102$ *minutes of total direct labor content (DLC). There are 3 workers, each with 60 minutes per hour available to them, so total time available is* 3 *workers* $\times 60\ \frac{minutes}{hour} = 180$ *minutes. Therefore:*

$$\begin{aligned} Utilization &= \frac{Direct\ Labor\ Content}{Time\ Available} \\ &= \frac{102\ minutes}{180\ minutes} \\ &= 56.66\bar{6}\% \end{aligned}$$

3. Charlotte hires a new worker (for a total of 4 including Charlotte). This new worker will also be dedicated to a single task, which will allow for parallel production of that task but will not shorten its processing time. Recall that parallel production means that workers can perform the same task on two *different* units simultaneously.

(a) To which task would you assign this fourth worker in order to maximize output rate?

A. Cut

B. **Assembly**

C. Paint

D. It does not matter which task you assign the fourth worker to.

Assembly, since it is the constraining resource (bottleneck).

(b) What is the constraining resource once the fourth worker is added?

A. Cut

B. **Assembly**

C. Paint

D. Charlotte

E. One of the workers besides Charlotte.

Assembly remains the constraining resource.

(c) What is the cycle time (in minutes per house) of the three-step process?

A. 3 $\frac{\text{minutes}}{\text{house}}$

B. 4 $\frac{\text{minutes}}{\text{house}}$

C. 5 $\frac{\textbf{minutes}}{\textbf{house}}$

D. 8.5 $\frac{\text{minutes}}{\text{house}}$

E. 17 $\frac{\text{minutes}}{\text{house}}$

Two parallel assembly tasks produce 2 houses every 10 minutes, so the cycle time is 5 minutes per house.

(d) What is the capacity of the three-step process (in houses per hour)?

A. 7.06 $\frac{\text{houses}}{\text{hour}}$

B. 12 $\frac{\textbf{houses}}{\textbf{hour}}$

C. 15 $\frac{\text{houses}}{\text{hour}}$

D. 16 $\frac{\text{houses}}{\text{hour}}$

E. 20 $\frac{\text{houses}}{\text{hour}}$

$60\ \frac{minutes}{hour} \times \frac{1\ house}{5\ minutes} = 12\ \frac{houses}{hour}$

(e) What is worker utilization?

A. 100%

B. 76%

C. $66.66\bar{6}\%$

D. 85%

E. $56.66\bar{6}\%$

Altogether, the workers work $17\ \frac{minutes}{house} \times 12\ \frac{houses}{hour} = 204$ *minutes of total direct labor content (DLC). There are 4 workers, each with 60 minutes per hour available to them, so total time available is* 4 *workers* $\times 60\ \frac{minutes}{hour} = 240$ *minutes. Therefore:*

$$\begin{aligned} Utilization &= \frac{Direct\ Labor\ Content}{Time\ Available} \\ &= \frac{204\ minutes}{240\ minutes} \\ &= 85\% \end{aligned}$$

4. Charlottes hires a new worker (for a total of 5 including Charlotte). This additional worker will also be dedicated to a single task, which will allow for (or increase) parallel production.

(a) To which task would you assign this fifth worker in order to maximize output rate?

A. Cut

B. **Assembly**

C. Paint

D. It does not matter which task you assign the fourth worker to.

Assembly, since it remains the constraining resource.

(b) What is the constraining resource once the fifth worker is added?

A. Cut

B. Assembly

C. **Paint**

D. Charlotte

E. One of the workers besides Charlotte.

Adding a new worker to the assembly step shifts the bottleneck to the paint step.

(c) What is the cycle time (in minutes per house) of the three-step process?

A. 3 $\frac{\text{minutes}}{\text{house}}$

B. 4 $\mathbf{\frac{\text{minutes}}{\text{house}}}$

C. 5 $\frac{\text{minutes}}{\text{house}}$

D. 8.5 $\frac{\text{minutes}}{\text{house}}$

E. 17 $\frac{\text{minutes}}{\text{house}}$

The paint step is now the bottleneck, so it determines the cycle time.

(d) What is the capacity of the three-step process (in houses per hour)?

A. 7.06 $\frac{\text{houses}}{\text{hour}}$

B. 12 $\frac{\text{houses}}{\text{hour}}$

C. 15 $\mathbf{\frac{\text{houses}}{\text{hour}}}$

D. 16 $\frac{\text{houses}}{\text{hour}}$

E. 20 $\frac{\text{houses}}{\text{hour}}$

$$60 \ \tfrac{minutes}{hour} \times \tfrac{1 \ house}{4 \ minutes} = 15 \ \tfrac{houses}{hour}$$

(e) What is worker utilization?

A. 100%

B. 76%

C. $66.66\bar{6}\%$

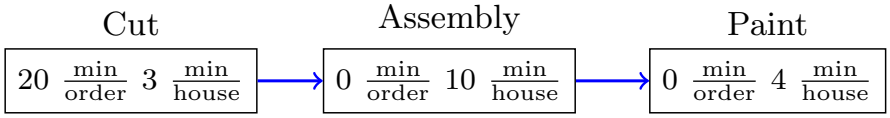
D. 85%

E. $56.66\bar{6}\%$

Altogether, the workers work $17 \ \frac{minutes}{house} \times 15 \ \frac{houses}{hour} = 255$ *minutes of total direct labor content (DLC). There are 5 workers, each with 60 minutes per hour available to them, so total time available is* 5 *workers* $\times 60 \ \frac{minutes}{hour} = 300$ *minutes. Therefore:*

$$\begin{aligned} Utilization &= \frac{Direct\ Labor\ Content}{Time\ Available} \\ &= \frac{255 \ minutes}{300 \ minutes} \\ &= 85\% \end{aligned}$$

5. Let's add another bit of complexity. What happens if Charlotte starts customizing houses and there is a 20-minute setup for the cutting process for each order? Her average order size is for 10 houses, and she has to leave her workers as assigned in part 4 above.



(a) What is the capacity (in houses per hour) if our average order size is 10 houses?

A. 12 $\frac{\textbf{houses}}{\textbf{hour}}$
B. 15 $\frac{\text{houses}}{\text{hour}}$
C. 16 $\frac{\text{houses}}{\text{hour}}$
D. 18 $\frac{\text{houses}}{\text{hour}}$
E. 20 $\frac{\text{houses}}{\text{hour}}$

The capacity of each step is now:

- Cut*:*

$$20\ \frac{min}{order} \times \frac{1\ order}{10\ houses} + 3\ \frac{min}{house} = 5\ \frac{min}{house}$$
$$5\ \frac{min}{house} \times \frac{1\ hour}{60\ min} = \frac{1\ hour}{12\ houses} \rightarrow \frac{12\ houses}{hour}$$

- Assembly*:*

$$0\ \frac{min}{order} \times \frac{1\ order}{10\ houses} + \frac{10\ min}{3\ houses} = 3.3\ \frac{min}{house}$$
$$3.3\ \frac{min}{house} \times \frac{1\ hour}{60\ min} = \frac{3.3}{60}\ \frac{hour}{house} \rightarrow \frac{18.\bar{1}8\ houses}{hour}$$

- Paint*:*

$$0\ \frac{min}{order} \times \frac{1\ order}{10\ houses} + \frac{4\ min}{house} = 4\ \frac{min}{house}$$
$$4\ \frac{min}{house} \times \frac{1\ hour}{60\ min} = \frac{1}{15}\ \frac{hour}{house} \rightarrow \frac{15\ houses}{hour}$$

(b) What is the cycle time (in minutes per house) of the three-step process?

A. 3 $\frac{\text{minutes}}{\text{house}}$
B. 4 $\frac{\text{minutes}}{\text{house}}$
C. 5 $\frac{\textbf{minutes}}{\textbf{house}}$
D. 10 $\frac{\text{minutes}}{\text{house}}$
E. 23 $\frac{\text{minutes}}{\text{house}}$

$\frac{1\ hour}{12\ houses} \times \frac{60\ min}{1\ hour} = 5\ \frac{minutes}{house}$

(c) What is worker utilization? (Remember we now have 5 workers)

A. 100%
B. 76%
C. 66.66$\bar{6}$%
D. 85%
E. 56.66$\bar{6}$%

Now we have an additional setup time of 20 minutes per order, for an additional $\frac{20\ min}{order} \times \frac{1\ order}{10\ houses} = 2\ \frac{min}{house}$*. Adding this to the direct labor content we calculated in Problem 4, Part (e), the direct labor content is now* $17\ \frac{min}{house} + 2\ \frac{min}{house} = 19\ \frac{min}{house}$*, so we have* $19\ \frac{min}{house} \times 12\ \frac{houses}{hour} =$

228 *minutes. There are 5 workers, each with 60 minutes per hour available to them, so total time available is* 5 *workers* $\times$ 60 $\frac{minutes}{hour}$ = 300 *minutes. Therefore:*

$$\begin{aligned} Utilization &= \frac{Direct\ Labor\ Content}{Time\ Available} \\ &= \frac{228\ minutes}{300\ minutes} \\ &= 76\% \end{aligned}$$