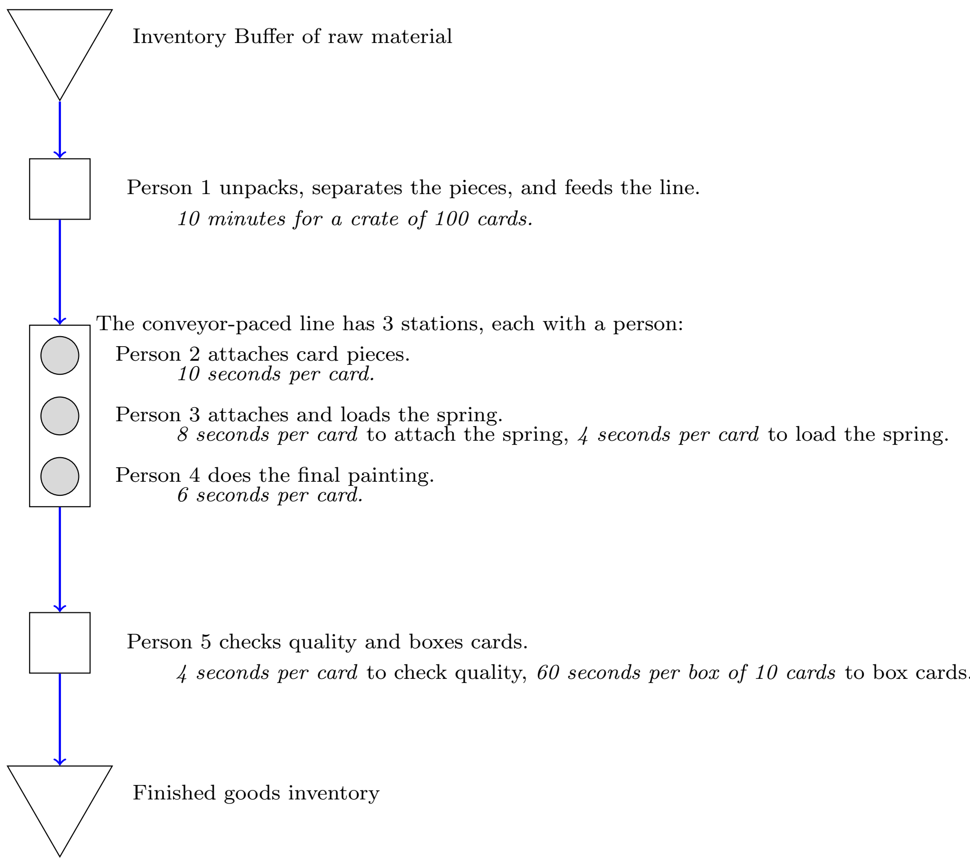
1. Myles has designed a new type of Holiday greeting card. The card involves combining several printed pieces, attaching a spring, loading the spring, a final hand painting touchup, and boxing the completed card. Since Holiday cards are seasonal goods, he sells them only during the 5 weeks between Thanksgiving and New Year's. During this time, he sells them at a constant rate 5 days a week and expects to sell 400,000 cards in the 5-week season. He creates an operating system to build the cards, which runs 8 hours a day (without breaks), 5 days a week. There are 5 workers who are all cross trained so that Myles can allocate tasks in different ways among the workers. Workers are paid for 8-hour days.



(a) Given the existing configuration, how many cards can he make in an 8-hour workday?

A. 300 $\frac{\text{cards}}{\text{day}}$

B. 480 $\frac{\text{cards}}{\text{day}}$

C. $2,400$ $\frac{\text{cards}}{\text{day}}$

D. $2,880$ $\frac{\text{cards}}{\text{day}}$

Line capacity is set by the bottleneck, Person 3's processing time, at $8+4=12$ $\frac{seconds}{card}$*:*

$$\frac{1\ card}{12\ seconds} \times 60\ \frac{seconds}{minute} \times 60\ \frac{minutes}{hour} \times 8\ \frac{hours}{day} = 2,400\ \frac{cards}{day}$$

(b) What is the utilization of the workers on the entire process?

A. $73.3\bar{3}\%$

B. $83.3\bar{3}\%$

C. 88%

D. 100%

$$
\begin{aligned}
&\textit{Direct labor content (DLC)} = \\
&\qquad \frac{10\ min}{100\ cards} \times 60\ \frac{seconds}{minute} \quad + && \text{(Person 1)} \\
&\qquad 10\ \frac{seconds}{card} \quad + && \text{(Person 2)} \\
&\qquad (8+4)\ \frac{seconds}{card} \quad + && \text{(Person 3)} \\
&\qquad 6\ \frac{seconds}{card} \quad + && \text{(Person 4)} \\
&\qquad (4\ \frac{seconds}{card} \quad + \frac{60\ seconds}{10\ cards}) && \text{(Person 5)} \\
&= (6+10+12+6+10)\ \frac{seconds}{card} \\
&= 44\ \frac{seconds}{card}
\end{aligned}
$$

In a conveyor-paced line, total labor time available to work on each unit is a function of the bottleneck: $12\ \frac{seconds}{worker} \times 5\ workers = 60\ seconds$. *Therefore:*

$$
Utilization = \frac{DLC}{Total\ Labor\ Time} = \frac{44\ seconds}{60\ seconds} = 73.3\bar{3}\%
$$

(c) Can he improve the speed of the system by rearranging the tasks?

A. Yes, by moving "Load Spring" to Person 4.

B. Yes, by moving "Check Quality" to Person 4.

C. Yes, by moving "Attach Spring" to Person 4.

D. No, the process cannot be improved in any way.

This question is asking whether workers could be reassigned to different tasks in order to shorten the cycle time of the bottleneck, but the task sequence cannot change. To do this we can move spring-loading to worker 4. Now the cycle time is 10 seconds, improving over the previous cycle time of 12 seconds. Utilization is now:

$$
\begin{aligned}
Utilization &= \frac{DLC}{Total\ Labor\ Time} \\
&= \frac{(6+10+8+10+10)\ seconds}{5\ workers \times 10\ \frac{seconds}{worker}} \\
&= \frac{44\ seconds}{50\ seconds} = 88\%
\end{aligned}
$$

(d) After rearranging tasks as in Question (c), what is the daily capacity of the line (in cards per day)?

A. $88\ \frac{\text{cards}}{\text{day}}$

B. $2,823\ \frac{\text{cards}}{\text{day}}$

C. $2,880\ \frac{\text{cards}}{\text{day}}$

D. $3,380\ \frac{\text{cards}}{\text{day}}$

$$60\ \frac{seconds}{min} \times \frac{1\ card}{10\ seconds} = 6\ \frac{cards}{min}$$
$$6\ \frac{cards}{min} \times 60\ \frac{min}{hour} \times 8\ \frac{hours}{day} = 2,880\ \frac{cards}{day}$$

For the next set of questions, continue to assume that now we have rearranged the tasks as in Question (c).

(e) Assume that each of the three stations on the conveyor belt is 1 meter long, and that the entire conveyor belt is 4 meters long (3 one-meter stations, plus a half a meter of excess space at the start and end of the conveyor belt). If he is producing with an output rate of 6 cards per minute, what is the throughput time (in minutes) of the cards to move through the conveyor belt step?

A. 0.16 minutes

B. 0.47 minutes

C. 0.5 minutes

D. 0.67 minutes

The cycle time of the belt step is the amount of time it takes the conveyor belt to move 1 meter, which equals 10 *seconds. The conveyor belt is 4 meters long, so:*

$$Throughput\ Time\ (TPT) = 4\ meters \times 10\ \frac{seconds}{meter} \times \frac{1\ minute}{60\ seconds} = 0.66\bar{6} \approx 0.67\ minutes$$

(f) He expects to sell 400,000 cards at an even rate over the 5-week season. Approximately, how many work days before the last work day of the season does he need to start producing cards if he has no initial inventory? Note that we can also produce cards during the selling period.

A. 12 days earlier

B. 46 days earlier

C. 114 days earlier

D. 139 days earlier

$$400,000\ cards\ \times 10\ \frac{seconds}{card} = 4,000,000\ seconds$$
$$4,000,000\ seconds \times \frac{1\ hour}{3,600\ seconds} \times \frac{1\ day}{8\ hours} = 138.8\bar{8}\ days \approx 139\ days$$

This assumes he has no cards on hand when he starts production (e.g., leftover from the prior year).

(g) Myles adds a WIP inventory buffer after the conveyor line before Person 5. The total average WIP in the operating system is 360 cards (not including raw materials and finished goods inventory). What is the average throughput time for cards, starting when they leave the raw material buffer to when they are put in the final goods inventory?

A. 20 minutes

B. 36 minutes

C. 50 minutes

D. 60 minutes

$$\begin{aligned} WIP &= OR \times TPT && \text{(Little's Law)} \\ TPT &= \frac{WIP}{OR} \\ &= \frac{360 \ cards}{6 \ \frac{cards}{minute}} \\ &= 360 \ cards \times \frac{1 \ minute}{6 \ cards} = 60 \ minutes \end{aligned}$$

Wait, can we use Little's Law here? Isn't this system not in steady state? We can use Little's Law because the part between the raw materials and finished goods is in steady state.

(h) The following questions examine inventory.

i. At what rate do the cards build up in his inventory? (in cards per day)

A. $879 \ \frac{\text{cards}}{\text{day}}$

B. $1,538 \ \frac{\text{cards}}{\text{day}}$

C. $2,880 \ \frac{\text{cards}}{\text{day}}$

D. $4,800 \ \frac{\text{cards}}{\text{day}}$

Before sales start, inventory builds up at:

$$6 \ \frac{cards}{min} \times 60 \ \frac{min}{hour} \times 8 \ \frac{hours}{day} = 2,880 \ \frac{cards}{day}$$

ii. Approximately, on what day are there the peak numbers of cards in inventory?

A. 46 days after production begins

B. 114 days after production begins

C. 139 days after production begins

D. 235 days after production begins

$$\begin{aligned} 138.8\bar{8} \ production \ days - 25 \ selling \ days &= 113.8\bar{8} \ days \ after \ production \ begins \\ &\approx 114 \ days \ after \ production \ begins \end{aligned}$$

iii. What is the peak number of cards in finished goods inventory?

A. 175,178 cards

B. 213,782 cards

C. 328,000 cards

D. 400,320 cards

$$113.8\bar{8} \ days \times 2,880 \ \frac{cards}{day} = 328,000 \ cards$$

iv. Remembering that cards are still being produced after sales start and could increase inventory if not sold, what is the net rate of inventory depletion once sales start? (in cards per day)

A. $13,120 \ \frac{\text{cards}}{\text{day}}$

B. $16,000 \ \frac{\text{cards}}{\text{day}}$

C. $19,120 \ \frac{\text{cards}}{\text{day}}$

D. $47,120 \ \frac{\text{cards}}{\text{day}}$

This question is asking about the rate at which inventory declines once the selling period has begun. The sales rate during the last 25 days is:

$$\frac{400,000 \ cards}{25 \ days} = 16,000 \ \frac{cards}{day}.$$

Some of this comes from that day's production $\left(2,880 \ \frac{cards}{day}\right)$*, and the rest is drawn from inventory, which diminishes. The inventory change is the day's production minus the day's sales, so the inventory change is:*

$$2,880 \ \frac{cards}{day} - 16,000 \ \frac{cards}{day} = -13,120 \ \frac{cards}{day}$$

v. Approximately, what are the total card-days of inventory? (in millions)

A. 18.7 million card-days

B. 22.8 million card-days

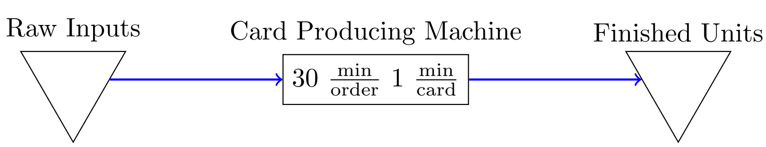
C. 37.1 million card-days

D. 45.6 million card-days

We can use the "triangle approach" here to calculate card-days of inventory. The width of the triangle (Figure 1) is the duration during which they have inventory ($138.8\bar{8}$ *days*)*, and the height is the maximum inventory* ($328,000$ *cards*)*. Therefore, using the formula for the area of a triangle* $\left(\frac{1}{2} \times \textit{width} \times \textit{height}\right)$*:*

$$\textit{Inventory} = \frac{1}{2} \times 138.8\bar{8} \ \textit{days} \times 328,000 \ \textit{cards} = 22,777,777.77 \ \textit{card-days} \approx 22.8 \ \textit{million card-days}$$

Calculating capacity when there is online setup.



vi. Refer to the new card producing machine Myles is considering purchasing in the diagram above. What is the capacity (in cards per hour) if the average order size is 10 cards?

A. $4 \ \frac{\text{cards}}{\text{hour}}$

B. $10 \ \frac{\text{cards}}{\text{hour}}$

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

D. $20 \ \frac{\text{cards}}{\text{hour}}$

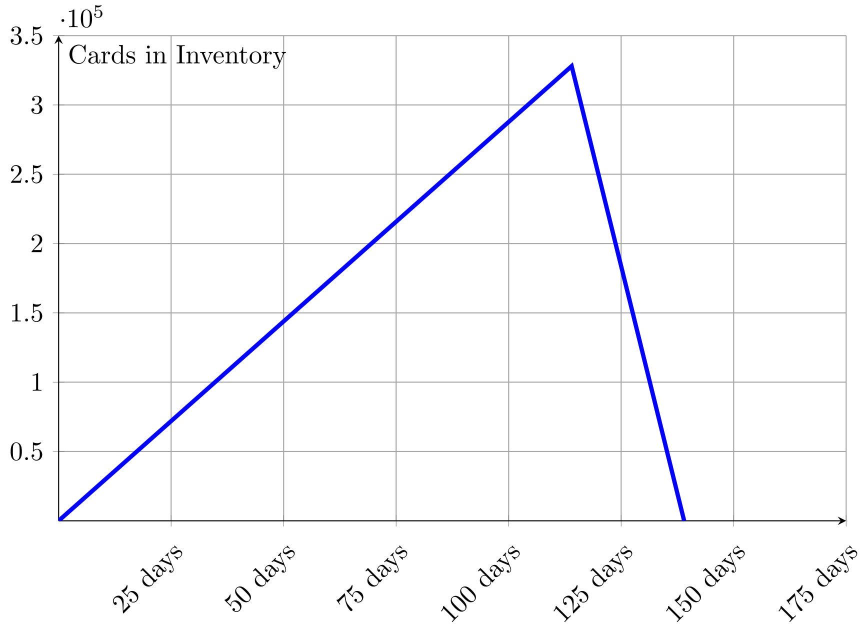


Figure 1: Buildup of Cards in Inventory

The cycle time per card for a 10 card order is:

$$\frac{30\ min + 1\ \frac{min}{card} \times 10\ cards}{10\ cards} = \frac{40\ min}{10\ cards} = 4\ \frac{min}{card}$$

so the capacity for a 10 card order is:

$$\frac{1\ card}{4\ min} \times \frac{60\ min}{1\ hour} = 15\ \frac{cards}{hour}$$

2. You arrive at a high-end, exclusive coffee café that is operating in steady state. The server starts serving the first customer in line immediately after you arrive. You have some information about the process, but not all of the information. You'd like to figure out the missing information.

   (a) If there are 5 people in front of you and it takes 3 minutes on average to serve each person, how long will you wait (in minutes) before the server starts to take your order?

      A. 2 minutes

      B. 5 minutes

      C. 15 minutes

      D. 18 minutes

$$\begin{aligned} WIP &= OR \times TPT && \text{(Little's Law)} \\ &= \frac{1}{CT} \times TPT && (\text{OR} = \tfrac{1}{\text{CT}}) \\ TPT &= CT \times WIP \\ &= 3\ \frac{min}{person} \times 5\ people = 15\ minutes \end{aligned}$$

(b) If you end up waiting 20 minutes before the server starts to take your order, and it takes the server 10 minutes on average to serve each person, how many people were in line when you first arrived?

A. 2 people

B. 3 people

C. 5 people

D. 15 people

$$\begin{aligned}
WIP &= OR \times TPT && \text{(Little's Law)}\\
&= \frac{1}{CT} \times TPT && (\text{OR} = \tfrac{1}{\text{CT}})\\
&= \frac{20\ minutes}{10\ \frac{minutes}{person}}\\
&= 20\ minutes \times \frac{1\ person}{10\ minutes}\\
&= 2\ people
\end{aligned}$$

(c) If you wait 30 minutes before the server starts to take your order, and there are 6 people in line when you arrive, what is the average time (in minutes) it takes to serve each customer?

A. $2\frac{\text{minutes}}{\text{person}}$

B. $3\frac{\text{minutes}}{\text{person}}$

C. $4\frac{\text{minutes}}{\text{person}}$

D. $5\frac{\text{minutes}}{\text{person}}$

$$\begin{aligned}
WIP &= OR \times TPT && \text{(Little's Law)}\\
&= \frac{1}{CT} \times TPT && (\text{OR} = \tfrac{1}{\text{CT}})\\
CT &= \frac{TPT}{WIP}\\
&= \frac{30\ minutes}{6\ people}\\
&= 5\ \frac{minutes}{person}
\end{aligned}$$

(d) You decide to go to a café with faster service. If you wait 20 minutes and the output rate is $2\frac{\text{people}}{\text{minute}}$, how long was the queue in front of you when you first arrived?

A. 2 people

B. 5 people

C. 10 people

D. 40 people

$$WIP = OR \times TPT \qquad \text{(Little's Law)}$$

$$= 2\ \frac{people}{min} \times 20\ minutes$$
$$= 40\ people$$

3. Consider the two process flow diagrams below. Processing times on all workstations are uniformly distributed; the numbers below each workstation represents the mean, in minutes, and the distance from the mean to the minimum value or to the maximum value. All processing times between the minimum and the maximum are equally likely. [For example, "6 ± 2" designates that the mean processing time is 6 minutes, and that all processing times between 4 minutes $(6 - 2)$ and 8 minutes $(6 + 2)$ are equally likely to occur].

Line A:

Task 1		Task 2		Task 3		Task 4		Task 5		Task 6
10 ± 2	→	10 ± 2	→	10 ± 2	→	10 ± 2	→	10 ± 2	→	10 ± 2

Line B:

Task 1		Task 2		Task 3		Task 4		Task 5		Task 6
6 ± 2	→	10 ± 2	→	4 ± 3	→	7 ± 1	→	5 ± 3	→	5 ± 2

(a) Which line will have the greater average output rate?

A. Line A

B. Line B

C. Line A and Line B have the same output on average.

D. Cannot tell from the information provided.

Line B will have, on average, the greater output. The key to this question is to recognize that, for Line B, the bottleneck, Workstation 2, is never starved or blocked by any of the other five workstations. Even at their slowest, all of the other workstations run at least as fast as 8 minutes per unit. Workstation 2 will always be at least as slow as that. For Line A, on the other hand, as we saw in the Process Simulator exercises, all of the workstations are, at times, blocked or starved, and thus all workstations will operate at more than their average cycle time of 10 minutes. The output of Line A will be less than the 6 units per hour that we would get from a line with no variability. The output of Line B, however, will be exactly 6 units per hour, on average. Thus the average output of Line B is greater than the average output of Line A.

(b) With the goal of increasing average output rate, if you could add one buffer, where in Line A would you put it?

A. Between the first and second workstations

B. Between the second and third workstations

C. Between the third and fourth workstations

D. Between the fourth and fifth workstations

E. There is no one single "best" location because no buffer would help to increase output

With the goal of increasing average output, if you could add one buffer to Line A, you'd put it between the third and fourth workstations. As we saw in the Process Simulator exercises, the best way to use a buffer in a line with equal processing-time distributions is to decouple the line into two lines of equal length.

(c) With the goal of increasing average output rate, if you could add one buffer, where in Line B would you put it?

A. Between the first and second workstations

B. Between the second and third workstations

C. Between the third and fourth workstations

D. Between the fourth and fifth workstations

E. There is no one single "best" location because no buffer would help to increase output

There is no one single "best" location because no buffer would help to increase output. As discussed above, Workstation 2 is never either blocked or starved by any of the five other workstations. Indeed, Workstation 2 paces the entire line. Consider placing a buffer anywhere after Workstation 2: units leave Workstation 2 every 8 to 12 minutes; all downstream workstations work faster than that. Thus the buffer would always be empty and have no effect on output. If we put a buffer between Workstation 1 and Workstation 2, it would fill up, but since Workstation 2 is never starved anyway, it would have no effect. The output of Line B is exactly identical to the output of Workstation 2 alone. Buffers have no effect on this line.